ADAPTATION TO CLIMATE CHANGE IN AGRICULTURE: EVALUATION OF OPTIONS

A report by

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Executive Summary

- The main purpose of this report is to develop a framework to consistently and systematically evaluate adaptation options in agriculture to climate change. It is intended to inform stakeholders in federal and provincial agencies, the research community, the agriculture and agri-food industry, farm organizations, and the general public about the evaluation of adaptation measures available in agriculture to deal with climate-related risks. It reviews approaches to evaluating adaptation options to climate change; demonstrates the applicability of the framework to agricultural adaptation in Canada; and identifies important constraints and opportunities for incorporating adaptations to climate in agricultural decision-making.

- Agriculture is inherently sensitive to climate conditions, and is among the most frequently cited human systems likely to be affected by global climate change. Although agricultural systems are vulnerable to the risks of climate change, they also have, to varying degrees, a capacity to cope with and adapt to changing conditions. It is recognized that adaptation in agriculture has the theoretical potential to moderate impacts, yet little research has been undertaken to identify those adaptations that either are *likely* to be adopted given climate change risks, those which *should* be adopted to ameliorate negative impacts of climate change, or those that *have* been adopted to address past and current climate risks, and other risks.

- Adaptation refers to responses by individuals, groups and governments to actual or expected climatic stimuli or their effects to reduce vulnerability to adverse impacts or damage potential, or to realize opportunities associated with climate change. This report focuses on adaptations undertaken or promoted as planned policy initiatives that represent changes in some attribute of the agricultural system (the agricultural sector or farms within it) directly related to reducing vulnerability to climate change.

- There is an immense number and variety of potential adaptation options available to deal with climate change risks. However, to determine which adaptations should be promoted or implemented (i.e., somehow judged to be best or of higher priority), adaptation options need to be evaluated. Evaluations are intended to assess the overall merit, suitability, utility or appropriateness of potential adaptation strategies or measures. It is expected that evaluation methods or frameworks will at least assist in screening potential adaptation options, and provide direction as to which adaptations should be encouraged or implemented.

- Adaptation evaluation as part of a planned policy response deals with consciously planned, primarily anticipatory adaptation initiatives undertaken by public (government) and private (agri-business and farmers) decision-makers. Consideration of who undertakes the adaptation and who benefits from the adaptation is a fundamental part of differentiating adaptations, and is necessary in any evaluation of adaptation options.

- Given the importance of a variety of criteria for adaptation evaluation in the agricultural sector, including but not limited to economic factors, one methodology has particular appeal: Multiple Criteria Evaluation (MCE). MCE is designed to assess alternatives using more than one criterion and aims to evaluate adaptation options relative to a range of different considerations or goals, not only on principally economic factors. Within this framework six criteria capture the range of concerns in the evaluation of adaptation options: (i) effectiveness; (ii) economic efficiency, (iii) flexibility; (iv) institutional compatibility; (v) farmer implementability; and (vi) independent benefits.

- To illustrate the utility of the evaluation framework at the level of a private agent (farmer), three adaptation options are selected: (i) crop diversification, (ii) adoption of irrigation, and (iii) increase use of crop insurance. At the level of a public agent (government), three adaptation options are selected: (i) increase investment (income stabilization programs), (ii) modify (reduce) crop insurance support, and (iii) promote crop development. Public-level adaptations are evaluated from both the farmer's point-of-view and the government's (general public) point-of-view. The results of the evaluation are shown using (i) simple unaggregated criteria scores; (ii) 'unweighted' sum of scores, and (iii) weighted sum of scores where differential weights are adopted.

- At the private level (farmer), crop diversification as an adaptation option has high flexibility and institutional compatibility, and variable effectiveness. Implementation of irrigation is variable across most of the evaluative criteria, given the possible different scenarios for water availability and accessibility, and institutional arrangements. Increased use of crop insurance is economically efficient, flexible, institutionally compatible and farmer implementable. Using either of scores or weighted sum MCE, increased use of crop insurance has the highest overall evaluation.

- At the public level (government), increases in income stabilization as an adaptation has high flexibility and independent benefits, but is not economically efficient from the government's point-of-view. Modification of crop insurance is economically efficient from the government's point-of-view, but scores poorly on farmer implementability and independent benefits. Promotion of crop development scores highly on farmer implementability, but has limited effectiveness, feasibility and independent benefits. Overall, from the farmer point-of-view, increasing income stabilization is evaluated most highly, whereas from the government point-of-view the modification of crop insurance is the superior public option.

- The examples employed in the evaluative framework illustrate that the MCE is technically possible, but that to evaluate in more than a superficial fashion, applications of the framework need to be considerably more specific (i.e., incorporate the nature of climate change stimuli, location attributes of the farm, personal characteristics of the farmer, circumstances of the farm operation, and the political propensities and economic constraints of different levels of government) and would need to consider explicitly temporal scales (i.e., short versus long-term).

- Both for private (farmer) and public (government) decision-making, evaluations of adaptations to climate change need to be taken as part of the on-going assessment of choices in light of climate and other risks.

- While it is possible to apply an evaluation consistently, it may not be the most practical or necessary exercise given that decisions or 'adaptations' represent facets of on-going management (and risk management) decisions in the agri-food sector. Climate change risks are experienced in the context of a wide range of other conditions (economic, social, political), and the evaluation of options to adapt to such risks is likely to be undertaken in the context of these broader decision processes.

- Quite apart from the technical challenges of MCE, and notwithstanding the information it can provide about the relative merits of adaptation options, the evaluation of adaptations to climate change, if intended to contribute to decision-making in the agri-food sector, must be included as part of the broader evaluation of measures and practices in this sector. A useful exercise in this regard is to consider of how climate change risks fit into the more general framework of agricultural decision-making.

1. Introduction

As a response to risks and impacts of climate change, adaptation has received increasing attention, and is now a fundamental concern of many governments and international negotiations (UNFCCC, 1992; Klein and MacIver, 1999; Smit *et al.*, 2000). Adaptation refers to responses by individuals, groups and governments, to climatic stimuli or effects to reduce vulnerability of, or susceptibility to, adverse impacts or damage potential. Adaptation can be directed to reduce potential negative consequences, or to benefit from opportunities associated with climate change (Carter *et al.*, 1994; Watson *et al.*, 1996; Pielke, 1998; Tol *et al.*, 1998; UNEP, 1998; Wheaton and MacIver, 1999; Smit *et al.*, 2000).

Agriculture is inherently sensitive to climate conditions, and it is among the most frequently cited human systems likely to be affected by global climate change (Rosenzweig and Parry, 1994; Smit *et al.*, 1996). Many impact studies have shown the vulnerability of the agricultural sector to climate change (Rosenberg, 1992; Budyko and Menzhulin, 1996; Reilly and Schimmelpfennig, 1999; Bryant *et al.*, 2000). However, agricultural systems also have, to varying degrees, a capacity to cope with and adapt to changing conditions (Reilly, 1995; Parry *et al.*, 1998). Compared with some sectors, agriculture is often considered to be especially adaptable. Changes with respect to technology, resources and management can be made relatively quickly and can be part of on-going adjustments in agricultural practices (Rosenberg, 1992; Mendelsohn *et al.*, 1994).

Assessments of climate change impacts in Canada and around the world commonly estimate the sensitivity of selected agricultural attributes (e.g., crop yield) relative to climate change scenarios (Brklacich *et al.*, 1997a; Bryant *et al.*, 2000). A noteworthy development in impact studies is the recognition that adaptations may occur autonomously in agriculture. Analyses that assume autonomous adaptation show greatly reduced losses (and often benefits) compared to those studies that do not assume adaptation (Rosenberg, 1992; Rosenzweig and Parry, 1994; Reilly, 1995; Mendelsohn and Dinar, 1999). The recognition that adaptation in agriculture has the theoretical potential to moderate impacts has prompted investigations into the possible forms and types of adaptation (Smit, 1993; Kandlikar and Risbey, 2000; Smit *et al.*, 2000; Skinner *et al.,* 2001). Yet, little research has been undertaken to identify those adaptations that either are *likely* to be adopted given climate change risks, those which *should* be adopted to ameliorate negative impacts of climate change, or those that have been adopted to address past climate and other risks. Estimates of adaptations that are likely to be undertaken autonomously, without new public policy initiatives, are important elements in assessments of climate impacts and vulnerabilities (Smit *et al.*, 1999; Smit *et al.*, 2000). This report focuses on adaptations undertaken or promoted as a planned policy response to concerns about climate change risks in the agricultural sector.

To determine which adaptations should be promoted or implemented (i.e., somehow judged to be best or of higher priority), adaptation options need to be evaluated. The outcome of such an exercise would be an assessment of the overall merit of alternative adaptation options; if not a ranking or scoring, then at least an identification of adaptations worth pursuing. Some generic evaluation frameworks have been proposed to judge the merit of planned adaptations to climate change generally (Smith and Lenhart, 1996; Klein and Tol, 1997) and agriculture specifically (Mizina *et al.,* 1999) in order to identify suitable adaptation options (Smith and Lenhart, 1996; Klein and Tol, 1997). This report reviews approaches to evaluating adaptation options to climate change, develops a framework to evaluate agricultural adaptations, demonstrates the applicability of this framework to agricultural adaptation in Canada, and identifies important constraints and opportunities for incorporating adaptations to climate in agricultural decision-making. While this report is a review of current adaptation knowledge from the climate impact, adaptation and vulnerability scholarship, it also incorporates information and insights from various stakeholders who undertake decisions in the agriculture sector. This information was gained through workshops and other communications with representatives from the scientific community, producer organizations, farm groups and government agencies, and individual producers.

2. Agriculture and Adaptation

A myriad of possible adaptation strategies for agriculture are presented in the literature (Smit, 1993; Kelly and Granich, 1995; Reilly, 1995; Reilly, 1996; Brklacich *et al.*, 1997a; Brklacich *et al.*, 1997b; Reilly and Schimmelpfennig, 1999). The suite of options range from routine management alterations by farmers themselves, such as changing timing of operations, adoption of conservation tillage practices and diversification in production systems, to investment of funds by public agencies in order to develop or improve irrigation schemes, modification of farm support programs, and development of new plant varieties (Smit, 1993; Skinner *et al.,* 2001). Adaptation options can be characterized according to a wide range of attributes including timing (reactive, concurrent or anticipatory), temporal scope (short- versus long-term), spatial extent (localized or widespread), and responsibility (individual, industry, government) (Carter *et al.*, 1994; Smithers and Smit, 1997; Smit *et al.*, 2000).

Reactive adaptations are those which occur after the impacts of climate change have been experienced, while anticipatory adaptations are pro-active, undertaken before the impacts are fully felt. Planned adaptations are generally anticipatory, but can also be reactive (i.e., adaptations are planned to be implemented once climate change effects are experienced) (Klein and Tol, 1997; MacIver and Dallmeier, 2000).

The adaptations available to farmers vary according to the local conditions and the particular farming system (Chiotti *et al.*, 1997; Smit *et al.*, 1999). Farmers can adapt tactically by changing the timing of operations such as planting and harvesting (Smit, 1993), or the timing of inputs such as irrigation (de Loë *et al.*, 1999) or fertilizers (Chiotti and Johnston, 1995). They can adapt by altering management practices such as tillage (Dumanski *et al.*, 1986) or drainage systems (Spaling, 1995), or their selection of crops and crop varieties (Smit *et al.*, 1996), or by diversifying the farm enterprise (Ilbery, 1991; MacKinnen *et al.*, 1991; Shaw and Hale, 1996; Bradshaw *et al.*, 2001). They can adapt via financial options such as using (or modifying use of) crop insurance (Smit, 1994), financial hedging or bank loans (Mahul and Vermersch, 2000; Turvey, in press), by using support programs or disaster relief programs of governments (Lewandrowski and Brazee, 1993; Smit, 1994), or by adopting various forms of off-farm income generation including off-farm work (Weersink et al, 1998; Bryant, 1989). Some impact studies have suggested 'adaptations' involving contractions and expansions of agricultural zones (Rosenberg, 1992; Brklacich *et al.*, 1997a). For producers, this would mean that some farmers would re-locate, or others would cease operations in some locations (or completely change the type of farming), whereas in other locations there would be new farmers or new types of farming by existing land owners.

While adaptations can be planned at the farm-level, the term 'planned adaptation' is generally used to refer to actions taken by governments as a conscious policy response (Klein and MacIver, 1999; Bryant *et al.*, 2000). These options aim to facilitate farm-level adjustments or enhance the adaptive capacity of the agricultural system (Skinner *et al.,* 2001). Possible planned adaptations involving governments include encouragement of technological adaptations, such as crop development (Smithers and Blay-Palmer, 2001) and early warning systems (Carlson, 1989), promotion of land and water use options (Chiotti and Johnston, 1995), assistance with changes in diversification or intensity of production (Brklacich *et al.*, 2000), and changed financial support in established programs and *ad hoc* compensation (Skinner *et al.*, 2001).

This report focuses on adaptations which represent changes in some attribute of the agricultural system (the agricultural sector or farms within it) directly related to reducing vulnerability to climate change. It is common in reviews of adaptation options to include activities, especially the provision of information on climate change and potential impacts, that may prompt consideration of adaptations, but that, in themselves, are not direct changes in the agriculture sector or farms within it (Bryant *et al.,* 2000; Skinner *et al.,* 2001). Certainly, the dissemination of information (on climate change, possible impacts and vulnerabilities, potential adaptation options, etc.) is something governments can do to promote adaptations, and it may be a necessary precursor to adoption of adaptation measures. However, in this report we consider information provision, dissemination and training as important parts of the means by which adaptation might be encouraged rather than as specific agricultural adaptations in their own right.

The likelihood of agricultural adaptation measures being adopted in response to climate change continues to be questioned, reflecting, in part, differing views over the climate-change stimuli to which farmers respond. Traditionally, weather (day-to-day conditions) and climate (longer-term average conditions) have been considered separately, although the two are essentially different perspectives on the same phenomena. Climate change includes not only long-term changes in average temperature, but also the year-to-year variation in growing season conditions, and the frequency and magnitude of extreme weather events (Parry and Carter, 1985; Smit *et al.,* 2000; Wandel and Smit, 2000). A major conclusion from the most recent IPCC (Smit *et al.,* 2001) is that the key features of climate change for vulnerability and adaptation are those relating to variability and extremes. Hence, adaptations in the agricultural sector are needed as much for the risks associated with inter-annual variability in growing season conditions and with the frequency and spatial extent of extreme climatic events, as for changes in average temperature or growing season length. While many farmers may be adaptable to changes in average climate, especially if they are gradual, the sector tends to be more vulnerable to changes in the frequency and/or magnitude of climatic conditions. Consequently, adaptations to changes in climatic variability and extremes will decrease vulnerability to climatic risks, both current and future.

There is considerable debate about the likelihood of farmers autonomously employing adaptations to climate change, about how such a process would occur, and about what the costs and benefits might be of relying on autonomous adaptations. Some climate impact modeling studies simply assume that farmers will completely and efficiently adapt to a predictable climate (Rosenzweig *et al.*, 1994; Mendelsohn and Dinar, 1999). However, studies of actual farmer decision-making show that autonomous adaptation is unlikely to be efficient or without costs (Smit *et al.*, 1996; Brklacich *et al.*, 1997b; Bryant *et al.,* 2000). Given the fact that climate change is experienced through year-to-year conditions, there are questions about farmers perceiving climate change risks (Smit *et al.*, 1996; Brklacich *et al.*, 1997b; Chiotti *et al.*, 1997; Smit *et al.*, 2000). Farmers tend to respond to changes which affect their income, and these result from the joint consequences of climate and market conditions and public programs. Changes in prices and costs, trade, subsidies and other government support programs may mask climate change effects, and thus dampen climate adaptation (Smit, 1994; Brklacich *et al.*, 2000; Bradshaw *et al.,* 2001). For individual farmers there are numerous personal, technical, investment and other economic constraints on changing locations, farm types and practices, and it would be naïve to assume that adaptations will be adopted simply because they have the theoretical potential to address a climate change impacts as risks.

3. Adaptation Evaluation as part of Impact Assessment

Adaptation is important in climate impact assessment because adverse impacts of climate change have the potential to be modified by various adaptation strategies (Easterling *et al.*, 1993; Rosenzweig and Parry, 1994; Reilly, 1995). Whether or not adaptation is assumed greatly influences whether climate change is judged to be problematic or beneficial for agriculture (Smit, 1993; Reilly *et al.*, 1994). Many studies attempting to predict what impacts might occur in agriculture with respect to climate change have presented adaptation as a modeling exercise based in part on assumptions about human responses (e.g. Easterling *et al.*, 1993; Rosenzweig and Parry, 1994). First-generation impact models assumed that no adaptations were employed (Smit *et al.*, 1989; Brklacich and Smit, 1992; Tol *et al.*, 1998), while second-generation models arbitrarily assigned adaptations and human coping strategies in response to climate change conditions that were assumed to be known (Easterling *et al.*, 1993; Mendelsohn *et al.*, 1994; Rosenzweig *et al.*, 1994). More recently, studies have begun to focus on the farm unit, addressing individual level responses and adaptations to temporal variations in climate conditions of relevance to farm-level decision-making (Smit *et al.*, 1996; Brklacich *et al.*, 1997b; Chiotti *et al.*, 1997; Smit *et al.*, 1997; Bryant *et al.*, 2000).

As part of impact assessments, researchers recently have attempted to estimate the overall impacts or damages of climate change, first without adaptation, then assuming adaptation. This comparison represents a type of evaluation of adaptation options by estimating the difference that adaptation can make to the costs (damages and benefits) of climate change (Fankhauser and Tol, 1997; Tol *et al.*, 1998; Schneider *et al.*, 2000). The value of damages avoided by adaptation are calculated and subtracted from the value of initial (without adaptation) impacts to estimate the residual costs of climate change impacts (Tol *et al.*, 1998). Estimates of damages in the impact literature generally combine adaptation costs (of investment or implementation) and the residual damage costs to identify a net damage figure. Theoretically, this approach could be applied in evaluating the relative merit of different adaptation options. Optimal levels of adaptation in terms of economic efficiency might be defined as those that minimize the sum of adaptation costs and residual damage costs (Fankhauser, 1996; Fankhauser and Tol, 1997).

Despite progress in conceptualizing adaptation damages, the practical application of this approach is limited. Not only is there little information on adaptation costs and residual damages, but the adaptation process itself is unclear (Fankhauser and Tol, 1997; Tol *et al.*, 1998). Impact assessments often assume that private agents will autonomously adapt, and that such adaptations will have net benefits (Wheaton and MacIver, 1999). There is also the need to go beyond assessing costs associated with static equilibrium climate scenarios, to estimate the transitional costs of dynamic adaptations to a changing and variable climate (Tol *et al.*, 1998). Researchers are also cautious about limiting evaluations to the single criterion of *economic efficiency*, given the importance of other economic, social, technical, environmental and political factors (Banuri *et al.*, 1996; Kane and Yohe, 2000; Smit *et al.,* 2001). This approach is more suited to impact assessment than to the evaluation of planned adaptation options.

4. Adaptation as a Policy Response

In addition to its role in impact assessment, adaptation is also an important policy option, and can be an alternative or complement to mitigation of climate change itself (Fankhauser, 1996; Smith, 1996a; Pielke, 1998; Smit *et al.*, 1999). The United Nations Framework Convention on Climate Change (UNFCCC) advocates the role of adaptation as a policy response by governments. Article 4.1b states that parties are committed to the development and implementation of programs at national and regional levels to mitigate climate change and to promote and facilitate adaptation. The Kyoto Protocol (Article 10) further commits parties to promote and facilitate adaptation and deploy adaptation technologies to address climate change. Agricultural adaptation as a policy response is regarded as an important influence in shaping agricultural decision-making and promoting adaptation at the farm-level, and in reducing the negative climate change impacts at the system scale. Adaptation policies can assist farmers in adjusting to climate changes, in mitigating damages and in realizing opportunities (Benioff *et al.*, 1996).

In order to promote or plan for adaptation, there is a need to evaluate available adaptation options. An *evaluation* goes beyond the identification and characterization of adaptation measures. Evaluation renders a judgement with regards to an adaptation option's relative merit, virtue, or superiority. Thus, evaluations are intended to assist decision-makers (producers, agri-business, governments) in deciding on whether or not to pursue adaptations and in their choice of adaptation options.

4.1 Evaluation of Planned Adaptations

Adaptation evaluation as part of a planned policy response deals with consciously planned, primarily anticipatory adaptation initiatives. Generally, adaptation evaluations have been conducted from the perspective of government decision-makers, but evaluation is also relevant to private agents who take consciously planned decisions (i.e. agri-business and individual producers). Evaluations are intended to assess the overall merit, suitability, utility or appropriateness of potential adaptation strategies or measures (Titus, 1990; Carter *et al.*, 1994; Goklany, 1995; Smith, 1996b; Smith and Lenhart, 1996; Fankhauser and Tol, 1997; Klein and Tol, 1997; Mendelsohn and Bennett, 1997; Stakhiv and Major, 1997; de Loë and Kreutzwiser, 2000). The focus of this report is on adaptation options as a conscious response (planned and anticipatory) to climate change in agriculture, by providing an evaluation of these options in order to judge their merit in advance of their adoption or deployment.

Climate change scholarship recognizes the importance of evaluation in identifying superior adaptation options. Some evaluations are resource specific, including water resources (Stakhiv, 1996; Frederick, 1997; Hurd *et al.*, 1997; Mendelsohn and Bennett, 1997; Stakhiv and Major, 1997; de Loë and Kreutzwiser, 2000), agriculture (Reilly, 1995, Mizina *et al.*, 1999), and forest ecosystems (Smith *et al.* 1996), while others address collectively a number of different sectors (Titus, 1990; Smith and Lenhart, 1996) or provide a more ubiquitous discussion of the general adaptability of natural resources and institutions (Goklany, 1995).

Attempts have been made to integrate evaluation of adaptation options into general frameworks of climate change impacts and responses (Carter *et al.*, 1994; Benioff *et al.*, 1996; Carter, 1996; Smith, 1996b). These provide general steps to identify resource sectors potentially vulnerable to climate change effects and adaptation constraints, and to assess potential adaptation options according to a number of pre-determined criteria, such as *flexibility*, *resilience* and *effectiveness*. The specification of criteria is a fundamental requirement of any evaluation method. Smith and Lenhart (1996) identify evaluative criteria, including *flexibility* and potential for *favourable benefit-cost analysis* in their evaluation of adaptation options for climate-sensitive sectors in Africa. In the area of water resource management, de Loë and Kreutzwiser (2000) suggested *flexibility*, *legal acceptability* and *economic efficiency* as criteria to identify appropriate adaptations as part of public policy responses. Evaluative criteria suggested by Titus (1990) also include *flexibility* (the ability of an adaptation to perform well for a range of likely climate changes), *economic efficiency* (benefits greater than costs), *urgency* (consequences of delayed implementation), *equity* (not helping some at the expense of others), *consistency* (ability of policy to support other national state, community or private goals), and *institutional feasibility* (whether policy is acceptable to the public and whether it can be implemented with existing institutions under existing laws). Similarly, in their evaluation of agricultural adaptation options in Kazakhstan, Mizina *et al.*, (1999) identify *flexibility* (options meet policy objectives under a wide range of climate change conditions) and *economic efficiency* (present value of benefits is greater than the costs) as two important criteria in identifying anticipatory adaptation options.

Effectiveness is often considered as a first step in adaptation evaluation. That is, unless an adaptation option is effective in meeting some target objective (e.g., reduced vulnerability to climate change, avoided climate change damages), it is illogical to consider it as a potential adaptation (Carter *et al.*, 1994; Smith, 1996a). Smith (1996b), using a hypothetical evaluation, illustrates the utility of identifying the *effectiveness* of various adaptation options in meeting specific objectives under alternative climate change scenarios.

Economic efficiency as a criterion is predominant in the adaptation evaluation literature (Titus, 1990; Smith and Lenhart, 1996; Mizina *et al.*, 1999; de Loë and Kreutzwiser, 2000). This suggests that adaptation strategies are justified when the additional adaptation costs are less than the additional benefits from the associated reduced damages (Fankhauser, 1996; Fankhauser and Tol, 1997). At the farm-level, a preferable adaptation option is one that is economically efficient or one that has economic benefits that outweigh costs. Perceived lack of profitability is among the most frequently cited constraints to adoption of a wide range of farm-level innovations. Land management decisions motivated by profit maximization are made in light of specific economic, technological and institutional constraints (Van Kooten, 1986). Lack of access to capital and land are common reasons for an inability to make a farm-level change or adopt an innovation (Napier *et al.*, 1984). Generally, if adaptation strategies are deemed economically inefficient, or if they do not benefit farmers at their expense, there may be little incentive to implement them, regardless of whether climate change impacts or risks are anticipated. While some studies dispute the notion of profitability as the sole motivator for adoption (see for example Bradshaw *et al.*, 1998), perceived profitability of adaptation options will likely increase acceptability of options by farmers.

While economic efficiency is a logical evaluative criterion, costing procedures for the evaluation of adaptation options pose a significant challenge, particularly in agriculture. For example, agricultural adaptation options are not always easily and clearly separable from day-to-day management decisions, and, therefore, not readily quantified in economic terms. Furthermore, the costs and benefits of adaptation are often shared by more than one party and, therefore, who bears the costs and/or benefits becomes a key concern (Skinner *et al.*, 2001).

The need for adaptations that are flexible, resilient and robust is common in the evaluation literature (Titus, 1990; Smith and Lenhart, 1996; Mizina *et al.*, 1999; de Loë and Kreutzwiser, 2000). Flexible decisions, particularly under extreme uncertainty and risk, have long been advocated in resource management scholarship, as these can more readily accommodate adjustments as new information or experience is gained (Collingridge, 1983). In the climate change literature, Mendelsohn and Bennett (1997) identified *flexibility* as an important criterion with regards to water allocation schemes and project analyses, given the current uncertainty in predicting potential climate change impacts.

Stakhiv (1996) evaluated the resilience of current water resource management to a variety of climate change effects, and concluded that existing practices have the capability to deal with climate change because they are resilient. Similarly, Frederick (1997) focused on robustness and flexibility to argue that existing institutions and planning processes can deal with climate change impacts. Given uncertainties of climate change effects, an evaluation of long-term projects to provide for a wider margin of safety to ensure system *flexibility* is offered as an alternative. Fankhauser and Tol (1997) and Smith and Lenhart (1996) agree that prevailing uncertainties constrain the identification, assessment and implementation of adaptation options. Given these uncertainties, they too suggest that adaptation options will essentially be limited to those that make the current system more flexible or robust. A fundamental concern for decision-makers is whether a decision should be taken now or deferred until a later date when there may be fewer uncertainties about climate change impacts. Given the expenses of new infrastructure and other programs to address potential future effects, it is logical to choose options that are flexible, such that if climate change impacts are different than expected, investments will still have utility (Titus, 1990). In agriculture, an adaptation option that is flexible is one that is functional in light of unforeseen climate changes and effects. For example, the choice of crop varieties that are tolerant to a wide range of climate conditions is considered a more flexible adaptation than planting crop varieties that are productive in very particular climate conditions.

Adaptations that are consistent with existing *institutional structures* and jurisdictional authority are more likely to be adopted than those that require changes to existing structures. Furthermore, as acknowledged in much of the climate change literature (Carter *et al.*, 1994; Carter, 1996; Smith, 1996a), existing laws, regulations and policies themselves can constrain the introduction of new programs that promote adaptation and can impede their utility in encouraging adaptive behaviour. As Adger and Kelly (1999, p. 258) note, adaptation "occurs through the actions of individuals facilitated or constrained by relevant institutions as well as through the actions of institutions themselves." Lewandrowski and Brazee (1993) note that while the prospects for adaptation in the agricultural sector to climate changes is good, these assumptions do not take into consideration policies that constrain beneficial adaptation options. It is generally believed that agriculture is one of the most adaptable sectors, given its flexibility to change practices, switch crop types and re-locate farming operations (Rosenberg, 1992). However, Lewandrowski and Brazee (1993) suggest that there are few incentives for farmers to make production changes given that government programs often subsidize irrigation water, support crop production in marginally suitable environments through price supports, and/or provide disaster relief in times of crop failure. However, this 'moral hazard' constraint may lesson as western governments act to decouple support payments from production decisions (OECD, 1998).

The ease with which an adaptation option can be implemented within an agricultural production system, apart from its institutional acceptability, is considered important. The decision-making environment in agriculture is complex and the implementation of an adaptation option into an often highly specialized production system is not always straightforward and simple (Brklacich *et al.*, 1997b; Smithers and Smit, 1997). The vast body of literature on diffusion of agricultural technologies confirms the importance of several characteristics of innovations relating to farmer implementability, such as lack of complexity, compatibility, triability and observability (Rogers and Shoemaker 1971). Complexity represents the degree to which new knowledge and skills are needed for implementation, and compatibility refers to the ease with which an innovation can be integrated into a current farming system. For example, an innovation that requires new skills and a multiple of incremental farm changes to be effective is probably less compatible than a simple adjustment in an existing management practice. Very rarely is an innovation universally or regionally applicable, and few innovations are discrete, identifiable technologies that are readily incorporated into an existing agricultural system with ease (Dunlop and Marten, 1983; Nowak, 1984; Heffernan and

Green, 1986). Adaptation options may represent site specific measures or management changes, and may require some alteration from their original form. For example, alterations in crop mixes and in the timing of planting represent farm management measures that are site specific and their form will vary depending on technological, environmental, social and economic circumstances specific to a particular farmer and farm operation. 'Triability', the degree to which an innovation may be experimented with prior to full adoption, and 'observability', the degree to which results of an innovation are visible to others, are also considered important considerations in promoting farm changes, and contribute to the implementability of adaptations. Overall, those measures that are compatible with others, have a high degree of observability and low complexity are more readily implemented (Vanclay, 1992).

Smith and Lenhart (1996) consider *net benefits independent of climate change* as an important attribute of adaptation options. They suggest that given current uncertainties in understanding the timing and effects of climate change, adaptations that will benefit the resource sector, regardless of whether or not climate change effects occur, are desirable. These strategies in agriculture recognize that adaptation policies will rarely be distinct from broader issues of agricultural production improvements and environmental sustainability). Essentially, adaptation options are preferred if they will result in no net losses (or damages) if expected climate change does not occur and if they will have benefits (i.e., improved productivity) independent of climate change ('no regrets' or 'win-win' measures) (Carter, 1996; Mizina *et al.*, 1999).

4.1.1 Evaluation of Adaptation Options by and for Whom

Evaluations of adaptations in some sectors, such as water resource management or coastal zone management, relate to adaptation initiatives that are primarily the responsibility of government agencies, at one level or another. Hence the evaluative criteria chosen tend to be consistent with the mandate and goals of governments or public agencies. In agriculture, adaptation decisions can be made by farmers, agri-business, and/or by governments, and decision criteria differ among these groups. Yet many discussions of agricultural adaptation consider types of adaptation without reference to who undertakes the adaptation and who benefits from the adaptation. For example, among potential agricultural adaptations commonly mentioned are new crop varieties, irrigation, timing of activities, and financial investment in crop development (Skinner *et al.*, 2001). Yet 'timing of activities' is primarily a farmer responsibility, with little role by governments or agri-business. 'New crop varieties' would be evaluated at the farm level as 'crop choice', at the business level as 'investment choice in crop breeding', and at the government level as 'public sector promotion of crop development'. So what may be evaluated highly by a farmer, may be of little utility (or even relevance) to business or government. This does not mean the actions of these groups are independent and not related. Actions and programs of governments can promote the adoption of adaptations by other agents (e.g., individuals) (Benioff *et al.*, 1996; Leary, 1999). Furthermore, certain programs of governments that represent adaptations at a sector scale (e.g., subsidized crop insurance) may serve to encourage and/or discourage other types of adaptation at the individual level (Smit, 1994).

The identification of who takes the action to adapt, what is changed or modified, and who benefits from the adaptation are not always explicit. These components of the adaptation process are particularly important in evaluating the value or merit of adaptation options (Smit *et al.*, 1999; Wheaton and MacIver, 1999; Reilly and Schimmelpfennig, 2000). Specifying who undertakes the adaptation is a fundamental part of differentiating adaptations (Smit *et al.*, 2000; Skinner *et al.,* 2001) and is necessary in any evaluation of adaptation options.

Consideration of the system (who or what) that is adapting is related to the issue of scale. For example, an adaptation at the individual or household level is different from one at the community, regional, and national level. For example, a change in management practices, such as a change in the timing of planting or the scheduling of irrigation is a farm-level adaptation to climate change. A regional adaptation might be the development of irrigation infrastructure or water pricing systems to manage water supply to an agricultural region. An adaptation at the national level might be a change in financial commitment to income stabilization programs or the sponsorship of crop development. It is impractical (and illogical) to compare a farm level adaptation to a regional or national scale adaptation because they involve different actors with different responsibilities and evaluative criteria.

Of course, some types of adaptations involve actions at several scales. A fundamental function of public policy, and a focus of adaptation in the policy arena, is the influence of policy on individual or private agent behaviour. Crop development, for example, may involve incentives at the national scale, research and advisory services at the regional scale, and change in crops at the farm scale. Furthermore, some national scale initiatives may discourage associated adaptations at the farm level and encourage others. For example, a government could adapt to increased risks associated with extreme climate events by reducing the subsidy on crop insurance to farmers, in order to address concerns over the costs and sustainability of public support. While the national scale adaptation strategy reduces the vulnerability of the taxpayer to increased economic burden, it makes crop insurance a more costly option at the farm level, perhaps increasing producer vulnerability and/or prompting other types of farm-level adaptation. Thus, an adaptation option implemented at the national level, for the benefit of the public system, does not necessarily translate into an adaptation for the private individual, although it may influence adaptations at the private level. Explicitly indicating for whom the adaptation option is intended to benefit is especially important in evaluations of adaptation options.

5. Methods for Evaluation of Planned Adaptation Options

The evaluative framework prepared by the IPCC (Carter *et al.*, 1994), along with others developed under its framework (Benioff *et al.*, 1996; Carter, 1996; Smith, 1996b; Klein and Tol, 1997), suggest various methodologies for the evaluation of adaptation options for public sector decision-making. These include benefit-cost analysis, cost effectiveness analysis, risk benefit analysis, multiple objective analysis, and multiple criteria evaluation.

5.1 Benefit Cost Analysis

Benefit-cost analysis (BCA) focuses on the economic benefits and costs of alternatives (Manning, 1987; Mitchell, 1997). It involves identifying all benefits and costs over the lifetime of a proposed adaptation measure, converting costs and benefits to a single metric; discounting the future value of benefits and costs; and calculating the ratio of benefits to costs. Benefits and costs are measured as monetary values so that they can be aggregated and compared. Those adaptations with the sum of discounted benefits exceeding the sum of discounted costs are considered preferable, and alternatives can be ranked according to a benefit-cost ratio (Toth, 2000). BCA determines the relative merit of an adaptation based on economic efficiency and is often applied in somewhat different forms than ratio, including difference or sum, to identify net benefits and costs (Fankhauser, 1996; Fankhauser and Tol, 1997).

Versions of BCA have been applied to evaluate the costs of adaptation to climate change (Nordaus, 1991; Titus, 1992; Tol, 1995; Tol, 1996). Fankhauser (1996) and Fankhauser and Tol (1997) evaluate adaptation alternatives according to economic efficiency based on the minimum sum of adaptation costs and residual damage costs.

Despite the apparent attraction of providing an aggregate cost or damage figure, BCA has limitations as a method to evaluate adaptations (Kane and Yohe, 2000; Toth, 2000). Conversion to a single monetary metric in BCA does not address distribution of benefits and costs, or whether inequities are increased or decreased. A BCA provides only aggregate values of these measures. Much detailed information is lost (e.g., what makes up the benefits and costs, their distribution) and this aggregation and oversimplification is of limited use and is generally not wanted by decision-makers. Also, conventional discount rates applied in BCA favour immediate benefits over longer-term benefits. Perhaps most importantly, conversion to a single monetary metric does not capture well, if at all, evaluative criteria other than economic efficiency.

5.2 Cost-Effectiveness Analysis

Cost-effectiveness analysis (CEA) is considered to be an implicit benefit-cost analysis (BCA), as the primary goal is to determine a strategy to meet a pre-determined objective as inexpensively as possible (Toth, 2000), or to determine the least-cost measure for reaching a specified goal (Smith *et al.* 1996). Smith *et al.* (1996) suggest a decision matrix as a cost-effectiveness example, where adaptation measures are compared according to the costs of adaptations, and the benefits of adaptations are estimated using a common metric, which does not necessarily have to be monetary in nature, but usually is. These measures are then calculated across the different objectives, and weighted or prioritized, to determine the most cost-effective measure. In practice, CEAs focus on economic criteria.

5.3 Multiple Criteria Evaluation

Multiple criteria evaluation (MCE) is designed to assess alternatives using more than one criterion (Hobbs *et al.*, 1992; Stakiv, 1992; Munda *et al.*, 1994; Smith, 1996b). This family of evaluation methods is distinguished by its explicit consideration of multiple criteria or objectives. These methods, sometimes collectively referred to as decision analysis, aim to evaluate adaptation options relative to a range of different considerations or goals, not only on principally economic factors. For adaptation evaluation in the agricultural sector, both public and private, such methods have particular appeal. When the multiple factors represent objectives, the name multiple objective analysis (MOA) is used, and the potential of alternatives meeting objectives is evaluated. When criteria are employed, the analysis is referred to as a multiple criteria evaluation (MCE). For our purposes, the methods are equivalent, and will be developed under the label MCE.

MCE requires adaptations to be evaluated separately on each of the chosen criteria, which usually involve quite different metrics (not only monetary). The results can then be presented in disaggregated form, reflecting a descriptive exercise. Often this method is sufficient and informative, allowing an individual user to apply a judgement regarding the relative importance of the various criteria. The results can also be transformed to a single index value by converting criteria values to comparative performance scores, thus allowing aggregation. A sum (or product) of the scores or an overall weighted sum can be calculated to reflect overall merit of each alternative. If taken to the step of aggregating to a single value, the MCE and BCA share the advantages and disadvantages of a single summary value; the essential difference between the two is that BCA is mainly economic whereas MCE considers multiple factors (Munda *et al.*, 1994).

Smith and Theberge (1987) identify two types of aggregation within MCE: compensatory and non-compensatory approaches. 'Compensatory' approaches are those where all criteria are measurable and comparable. The *additive weighting* or *weighted sum* method is among the most common compensatory MCE. All criteria are converted to comparable units (e.g., relative to some base policy goal or best options), and assigned weights according to their importance in meeting some objective or significance as deemed by decision-makers. Generally, weights are quantified on a ratio scale, using one or more methods. For example, Hobbs *et al.* (1992) distinguish between the direct weighting and indifference trade-off methods. In the first method, the decision-maker assigns a value to each criterion representing importance. In the latter method, the decision-maker determines how much of one criterion they would be willing to trade for a given improvement in another criterion, and then weights are calculated to represent these assigned trade-off judgements. There are a variety of other methods used to assign weights to criteria, including fixed point or value scoring, ordinal ranking, such as the expected value method, swing weighting and paired comparisons, including the analytic hierarchy (Hobbs, 1980; von Winterfeldt and Edwards, 1986; Saaty, 1987; Nijkamp *et al.*, 1990; Stakiv, 1992; Stewart and Scott, 1995; Hajkowicz *et al.*, 2000). The underlying premise of weighting is that a criterion that is considered twice as important as another should have a weight twice the value, and that all weights should represent the rate at which an evaluator(s) is willing to trade-off one criterion for another.

Each criterion score is then multiplied by their respective weights and the sum of values across criteria is calculated for each alternative. The assigning of weights involves measuring preferences and assigning numerical values to represent these preferences. Application of the weighted sum method is most appropriate when the desirable outcome is the choice of alternatives representing high overall value with respect to any of the individual criteria (Smith and Theberge, 1987). If the desired outcome is the identification of alternatives representing especially significant qualities for a single criterion, the weighted sum approach may hide these alternatives.

'Non-compensatory' approaches are those where criteria are measured on different scales and therefore cannot be directly compared.

There are various non-compensatory models such as those that rank alternatives based on either the weakest or strongest criterion value and disregard the other criterion values. Other approaches, such as the *conjunctive* method, set minimum standards and evaluate alternatives based on their ability to meet acceptable standards across all criteria. Similarly, *disjunctive* models evaluate alternatives according to their ability to meet a minimum standard for at least one criterion regardless of the overall value of the alternative. Disjunctive models are useful when the identification of alternatives that have especially high values for a single evaluative criteria is important, rather than the consideration of an average total value across all criteria (Smith and Theberge, 1987). MCE also allows for mixed methods, such as where options must meet some minimum standard for several or all criteria, and only then are they evaluated by a summative algorithm.

6. Selection of Criteria for the Evaluation of Agricultural Options

Given the importance of a variety of criteria in the evaluation of possible agricultural adaptations, including (but not limited to) economic factors, the MCE approach was adopted here. However, before applying the analysis, it is important to review the evaluative principles or criteria upon which to assess the various adaptation options.

6.1 Guidelines for Selecting Evaluative Criteria

The selection of criteria themselves and the method of judging performance of options on criteria are especially important in MCE and should not be arbitrary (Hobbs *et al.*, 1992). Evaluative criteria should satisfy a set of conditions.

First, all criteria should be relevant to the overall objective of the exercise, in this case to decrease agriculture's vulnerability to climate change, and offset potential negative effects of climate change (Rosenberg, 1992). The selection of criteria should be guided by their relevance to this objective. Second, the criteria must be non-redundant, in the sense that performance on each criterion must vary significantly between at least some of the adaptation options. Third, the criteria must have directionality -- that is, be defined in a way that higher or lower levels of performance can be interpreted as better or worse. Fourth, criteria should have some degree of measurability. It should be possible to estimate relative levels of performance for each adaptation alternative on each criterion. Fifth, each criterion should be logically independent of other criteria. Essentially, there should be no double-counting, as each criterion should capture a different basis for assessment and add distinct value to the evaluation. Sixth, manageability is also important in that too many criteria make the process unwieldy and difficult to interpret, and invites duplication. Experience shows that no more that ten criteria should be used in an evaluation.

6.2 Criteria for the Evaluation of Agricultural Adaptation Options

After applying these guidelines to the variety of evaluative criteria suggested in the literature (Section 4), six criteria were selected to capture the range of concerns in the evaluation of agricultural adaptations, and to do so in a way that is manageable, non-redundant, non-duplicative, and systematic. The criteria are: effectiveness, economic efficiency, flexibility, institutional compatibility, farmer implementability and independent benefits.

6.2.1 Effectiveness

An adaptation option is viewed more favorably, *ceteris paribus*, the more effective it is in achieving the objective of reducing vulnerability to climate change risks. An adaptation that, if implemented, only slightly reduces vulnerability of agriculture to climate change effects, would be less effective than one that greatly reduces the risks. Brklacich *et al.* (2000) identify the importance of effectiveness in considering the merit of an adaptation options in improving agricultural capacity to adapt to climate changes.

6.2.2 Economic Efficiency

Conventional cost-benefit exercises are important in evaluating anticipatory adaptation options. Projects and programs implemented by governments are preferable if they are *economically efficient* -- that is, they have economic benefits that exceed economic costs. Essentially, adaptation options where the potential costs of implementation are exceeded by the potential costs of foregone damages associated with the adaptation measure are considered superior. Similarly, from the perspective of private agents, adaptation options are deemed more desirable when the potential implementation costs are less than the potential damages that have been averted due to implementing the adaptation.

6.2.3 Flexibility

Flexible adaptation options reduce vulnerability to risks of climate change and variability and function in light of a range of climate conditions, not simply a particular projected condition. For example, a management strategy, such as crop choice, that reduces risks under a wide range of moisture and temperature conditions is more flexible than one that would produce exceptionally in a narrow range of conditions, but would be vulnerable to conditions outside that range.

6.2.4 Institutional Compatibility

An adaptation option is considered superior, the more it is consistent with existing laws, regulations and institutional structures (Titus, 1990; Mortsch and Mills, 1996; de Loë and Kreutzwiser, 2000). In agriculture, adaptation options that are constrained by institutional structures are less preferable to those that are compatible with these structures. For example, the implementation of irrigation or the diversification of farm operations are considered to be more desirable if institutional structures exist to promote their implementation and assist in their uptake, and if their adoption will not result in negative trade-offs in other areas of farming (e.g., decrease in ability to take advantage of farm assistance programs).

6.2.5 Farmer Implementability

Adaptation options are considered better, *ceteris paribus*, the more implementable they are (i.e., the more readily they can be adopted) in terms of farmer decision-making, technical and managerial ease, and acceptability within existing social norms. Innovation complexity is widely regarded as a constraint or a limiting factor in the technology transfer process. Complexity is the degree to which an innovation is perceived as difficult to understand and use, and has been found to be a common constraint or reason for non-adoption (Rogers and Shoemaker, 1971; Chamala, 1987). In general, new innovations that require little additional learning, effort and investment by a potential adopter will be implemented more rapidly than those that require the development of new skills and understanding, and are therefore representative of adaptations that have high farmer implementability. An adaptation option may be readily transferred from the research environment, and be in accordance with farmers' needs, but may not be accepted because of lack of understanding by farmers themselves (Guerin and Guerin, 1994). Adaptation options that lack complexity, are compatible with existing property and farm characteristics, and have a high degree of observability and triability are considered to have high farmer implementability and hence preferable to adaptations that do not have these attributes.

6.2.6 Independent Benefits

An adaptation strategy is viewed more favorably, *ceteris paribus*, the greater the benefits it brings, quite apart from (or in addition to) its contribution to reducing/avoiding risk associated with climate change. Many agricultural adaptations offer benefits beyond that of reducing vulnerability to climate change. For example, soil conservation measures encourage soil moisture retention, therefore reducing vulnerability to drought conditions. However, soil conservation measures also reduce potential for wind and water erosion, promote in soil fertility, and may enhance carbon sequestration. These benefits, independent of reducing vulnerability to climate change, are considered positive features of adaptations.

7. Multiple Criteria Evaluation of Agricultural Adaptation Options

In this section, the multiple criteria evaluation (MCE) method is illustrated via an application to several agricultural adaptation options. Decisions about adaptation measures are taken by both private agents (notably farmers) and public agencies (notably government bodies). The applicability of MCE to both types of decision-maker is illustrated in the examples. Because adaptation options differ between public agents (governments) and private agents (farmers) and because the criteria tend to differ between these two groups, evaluations need to be user-specific. To illustrate this, we apply MCE of adaptation options separately to public and private decision-makers.

7.1 Private Agents

Most adaptations will have varying utility according to the type of farming and its location. Dryland farming in southern Alberta is used to illustrate an application at the private level. Dryland agriculture is the dominant cropping agriculture in Alberta and is a major component of Alberta's agricultural economy. Crop agriculture in Alberta is dominated by wheat and small grains, including barley, canola, oats, flaxseed, rye and hay and most of these are grown under dryland conditions (Alberta Agriculture, 1999-2001).

Climate is an important factor influencing the variety, amount and yield reliability of these crops (Thompson, 1981). While irrigation allows for improved agricultural productivity and diversification of crops in warmer and more arid regions of the province, irrigated land constitutes only five percent of the total cultivated acreage (Alberta Agriculture, 1999-2001). Climate change and variability pose a serious threat to dryland agriculture in Alberta due to the potential for warmer and drier conditions, as well as the potential for changes in the frequency and magnitude of extreme events, particularly drought. With the prospect of climate change, farmers can adopt a variety of adaptation options to reduce the potential of climate-related losses or take advantage of climate-related opportunities. The objective here is to provide an evaluation of the relative merit of selected adaptation options to dryland crop farming in Alberta. This involves an evaluation of one adaptation relative to others for dryland farmers generally. A related but different kind of evaluation focuses on the likelihood of adoption by a particular farmer, in which case the evaluation would include more specifics of the individual operator's circumstances (e.g., finances, attitudes, investments, planning horizon). In our application, the framework is applied generally, intended to be representative of dryland farmers in southern Alberta, rather than applied specifically to a particular farmer.

7.2 Public Agents

While farmers themselves can adopt measures to adapt to climate-related risks, public agents, such as the federal and provincial governments, can also take policy and program initiatives that represent system-wide adaptations or that are designed to influence the adoption of farm-level adaptations. For example, government subsidy of crop insurance represents a sector-wide adaptation to climate risks involving decisions by public agencies (federal and provincial governments). A change in the level or nature of government support of crop insurance would have implications for farmers and for their use of crop insurance as part of a risk management or an adaptation strategy, in this case a financial adaptation measure. From a government point-of-view, an initiative such as increasing or reducing the subsidy of crop insurance would also have implications for government finances and for taxpayers.

Another example of a government initiative that influences farm-level adaptation is the promotion of crop development. Governments may play a role by targeting the development of crops (e.g., via in-house research or sponsorship of private sector development). New crops are then available for farmers who may choose to use them. Irrigation is another example. Implementation of irrigation represents an adaptation measure, assuming that water is available (at some cost). Adoption of irrigation involves an assessment by farmers with regards to technological, management and economic attributes. For governments, the issue may be whether or not to modify water use rights and arrangements (to make more readily available for irrigation) and to establish rules and regulations, such as pricing structure, or to build irrigation infrastructure. In this hypothetical case example, the adaptation options are evaluated in terms of their value or overall merit for the farm sector in dealing with climate-related risks.

7.3 Climate Change Risks (What Are Farmers Adapting To?)

An evaluation of adaptation options requires some indication of the climate change risks to which the adaptations pertain. The stimulus to which farmers are adapting to is a function of the relevant climate characteristics and relationship of these characteristics with the system that adapts (Pittock, 1999; Smit *et al.*, 1999). In this example, the climate change risk is that of income loss due to crop failure as a result of increased incidence of moisture stress and drought conditions. We focus on these climate-change risks because the literature on vulnerability of dryland farming to climate shows that the frequency and severity of drought matters to crop production and income (Chiotti and Johnston, 1995). These are climate attributes that are identified as significant by producers. Furthermore, there is some evidence that with climate change, the frequency and duration of droughts in the semi-arid regions of the Canadian Prairies will increase (Williams *et al.*, 1988; Herrington *et al.*, 1997). The proposed adaptation options (both public and private) reflect the intent to reduce the risk of farm-level income loss, which is a function of crop losses associated with the frequency and magnitude of droughts.

It is also important to identify the time frame for which the adaptation options are being evaluated. In this case, a five-year period is employed, since the particular climate-change risk is a function of a change in frequency over time, and not a change in mean (annual average) climate conditions.

7.4 Evaluative Criteria and Scoring

The criteria employed in the MCA are those selected earlier in Section 6.2. Given the role of MCE in providing an assessment over several criteria, there is a need to specify the units or metrics by which each criterion is evaluated. For example, *effectiveness* may be measured as a dollar value of losses avoided, *institutional compatibility* as an absolute number (i.e., count) of institutional structures that explicitly permit and/or encourage an adaptation option, and *economic efficiency* as a benefit/cost ratio. When MCE results are presented in disaggregated format, the scores can remain in the units most appropriate for each criterion. For aggregating over criteria, to generate an overall evaluation, the scores need to be standardized. We indicate a means of measuring the performance on each criterion, and show how each can be converted to a normalized comparative scale. A variety of procedures exist for normalizing or converting directly measured criterion scores to a standard comparative scale. For illustrative purposes, we employ a rating scheme, similar to a Likert-type scale, that represents the performance of each adaptation option against each criterion. The scale employs five categories (from 1 to 5) representing a very poor score (value of 1) to a neutral score where there is neither a poor nor high score (value of 3) to a very high score (value of 5). Other scales, such as a monetary scale or a ratio scale exist, but are not explored here.

7.4.1 Effectiveness

Effectiveness refers to whether or not the adaptation option actually reduces vulnerability to, and/or enhances opportunity to take advantage of the effects of climate change. In this example, effectiveness refers to the ability of, the adaptation option to reduce income loss as a result of increases in frequency and magnitude of drought. A very effective adaptation option will eliminate the risk of income loss, while an ineffective adaptation option will not greatly change this risk. Therefore, those options that eliminate the risk of income loss are more desirable and will receive a higher score than those that do not reduce risk.

Effectiveness can be measured in a number of ways. For example, a numeric scale is possible, measuring the monetary amount or percentage value of expected loss averted by the adoption of the adaptation option. This might involve economic modeling. Alternatively, adaptations might be assessed for effectiveness according to an ordinal scale or categories, based on estimates by informed researchers and stakeholders. Whatever the original metric, the evaluations can be converted to five categories of effectiveness (i.e., very ineffective, ineffective, neutral, effective, very effective) (Figure 7.1). To illustrate the conversion from a monetary scale, 'moderately effective' could be defined where a measure averts between 20% and 50% of expected income loss, whereas 'very effective' averts greater than 50% of loss.

1	2	3	4	5
very ineffective	*ineffective*	*neutral*	*moderately effective*	*very effective*

Figure 7-1 Effectiveness Scale

7.4.2 Economic Efficiency

Economic efficiency refers to the economic benefits of the adaptation relative to the economic costs of implementing the adaptation option. While potential benefits and costs can be measured in monetary terms, economic efficiency is commonly measured as the ratio of benefits to costs. The value of this ratio can be used to establish levels of efficiency and represented in the Likert scale. For example, an adaptation option, which has a benefit-cost ratio greater than 1.5 may be designed as very economically efficient, ratios between 1.1 and 1.5 are moderately efficient, ratios between 1 and 0.9 are of neutral efficiency, ratios between 0.9 and 0.8 inefficient, and ratios less than 0.8 are very inefficient (Figure 7.2).

1	2	3	4	5
very inefficient	*moderately inefficient*	*neutral*	*moderately efficient*	*very efficient*

Figure 7-2 Economic Efficiency Scale

7.4.3 Flexibility

Flexibility refers to the ability of the adaptation option to function under a variety of climate change conditions. For example, a very flexible adaptation option will avert income loss, whether the frequency of drought increases by 0%, 5%, 20%, 50% or 100%, and whether there are changes in the magnitude, timing or duration of moisture stress conditions, and perhaps associated heat stress or other related problems. An adaptation option that will only reduce income loss under a very particular set of climate conditions, and is ineffectual for other climate change conditions, is considered to be inflexible. Measurement of flexibility could be based on formal probability assessment, such as the ability to cope with specified drought frequency regimes and their associated risks. In this analysis, flexibility is measured directly on the five point Likert scale (Figure 7.3).

1	2	3	4	5
very inflexible	*moderately inflexible*	*neutral*	*moderately flexible*	*very flexible*

Figure 7-3 Flexibility Scale

7.4.4 Institutional Compatibility

This criterion refers to the degree to which adaptation options fit within existing institutional and legal structures. For example, are the necessary statutes and regulatory frameworks available to implement the adaptation option? Those options where institutional conditions support adoption are considered to be very compatible, while those options where statutes, regulations and other institutional frameworks do not exist for implementation, or where existing institutions constrain and/or prohibit implementation, are considered to be very incompatible (Figure 7.4).

1	2	3	4	5
very in-compatible	*moderately in-compatible*	*neutral*	*moderately compatible*	*very compatible*

Figure 7-4 Institutional Compatibility Scale

7.4.5 Farmer Implementability

Implementability refers to the ease with which an adaptation option can be implemented by a farmer given existing management, established practices, farmer values and resources. In this example, an adaptation option that has a high degree of understandability, observability and compatibility with operations is considered to have a high degree of farmer implementability (Figure 7.5). Those that have a high degree of complexity, and are not socially and culturally acceptable, and/or do not fit readily with established management practices, investment strategies or technology are considered to have very low farmer implementability.

1	2	3	4	5
very low implement-ability	*moderately low implement-ability*	*neutral*	*moderate implement-ability*	*very high implement-ability*

Figure 7-5 Farmer Implementability Scale

7.4.6 Independent Benefits

Independent benefits refer to the ability of an adaptation option to generate benefits independent of climate change. Those adaptation options that reduce the risk of income loss regardless of climate change are more desirable to farmers than options that are helpful only in addressing climate change risks, or that require some kind of trade-off (Figure 7.6). For example, an adaptation that represents high trade-offs is one where a farmer must give something up in order to adapt to the risk of climate change (e.g., must forfeit income to adapt). An adaptation that has neither trade-offs nor independent benefits is considered to have neutral independent benefits

1	2	3	4	5
high trade-offs	*moderate trade-offs*	*neutral*	*moderate in-dependent benefits*	*high in-dependent benefits*

Figure 7-6 Independent Benefits

7.5 Aggregation Over Multiple Criteria

There are several forms of multiple criteria evaluation. Three forms were adopted here. The first method is an evaluation over multiple criteria with the criteria scores left in their particular units. Each adaptation is evaluated separately according to each criterion. Alternatively, it is possible to aggregate over the criteria to generate a single evaluative score for each adaptation option. So long as the criteria scores use a common or comparable evaluative scale (i.e., a numerical scale, including ordinal and Likert categories), the scores can be summed to generate a single measure, representing an overall evaluation of each adaptation option. Another common MCE aggregation method, illustrated in the following section, is the weighted sum of scores. This method is essentially the same as the unweighted sum method above, but each criterion is weighted according to their relative importance. Each criterion score is multiplied by the assigned criterion weight before the values are summed to establish a single evaluative measure for each adaptation option.

7.5.1 Assigning Weights to Evaluative Criteria

In any evaluation exercise involving multiple criteria, there is some kind of weighting exercise, whether implicit or explicit. The mere selection and specification of criteria represents the most fundamental type of weighting, which is often not acknowledged. In identifying and implementing the criteria above, we have already implicitly assigned weights. However, a subsequent evaluative step can be undertaken where each selected criterion is explicitly assigned a weight according to its significance or importance relative to the other criteria.

The assigning of weights to each criterion is a subjective exercise and can be completed in a variety of ways. If MCE was to be employed by individual farmers, they could assign their own weights, reflecting their personal values, goals and expectations. For an application to dryland farming generally, weights could be assigned based on consultations with farmers, producer organizations, advisory personnel, and so on. For public agencies, weights may be assigned by government decision-makers, expert panels, or through a public participation process.

In this illustration of MCE to agricultural adaptations, we have not gone through a formal process to assign criteria weights, but have arbitrarily assigned weights for demonstration purposes (Table 7.1). The weighting structure employed here distributes weights among the criteria so that they represent relative shares of ten (Maclaren, 1985). In this case, effectiveness, for example, is three times as important as institutional compatibility, but of equal importance as economic efficiency.

Table 7-1 Criteria Weighting

Criterion	Weight
Effectiveness	3
Economic Efficiency	3
Flexibility	1
Institutional Compatibility	1
Farmer Implementability	1
Independent Benefits	1
Total	**10**

In this illustration, we show results in a format that permits three kinds of MCE: (1) simple unaggregated criteria scores, (2) 'unweighted' sum of scores, based on the assumption that the criteria are of equal importance, and (3) weighted sum (i.e., sum of products).

7.6 Adaptation Options and Their Evaluation

There is a wide variety of adaptation options that private agents (i.e., farmers) and public agents (i.e., governments) can potentially adopt (Smit, 1993; Bryant *et al.*, 2000; Skinner *et al.*, 2001). Adaptation decisions at the farm level involve changes in the use or deployment of management, technological or financial options, whereas at the government level the decisions involve programs to facilitate or encourage farmer adaptation, including research, institutional arrangements and income stabilization programs (Skinner *et al.*, 2001). To illustrate the evaluation framework at the farm level, three adaptation options are selected, representing each of the adaptation categories chosen:

1. crop diversification (management adaptation)
2. adoption of irrigation (technological adaptation)
3. increase use of crop insurance (financial adaptation)

At the level of government decision-making, three adaptation examples are chosen:

1. increase investment (income stabilization programs)
2. modify (reduce) crop insurance support (institutional arrangements)
3. promote crop development (research)

7.7 Evaluation of Private Agent (Farmer) Adaptations

This section applies the evaluation framework to the selected adaptation options, using available information and hypothetical scores, rather than based on systematic analyses or stakeholder processes. The evaluations for both private and public agents are intended to be illustrative of the MCE framework only, and the results from this illustration are not meant for use in actual policy-related decisions. The criteria scores of private agent adaptations are presented in Table 7-2.

7.7.1 Adaptation Option 1: Crop Diversification (Management Adaptation)

Diversification in agriculture is recognized as an adaptation or risk management response to changes in climate and to other market-related conditions (Helmberger and Chavas, 1996; Knutson *et al.,* 1998; Bradshaw *et al.,* 2001). While 'diversification' in agricultural production takes on many forms and is subject to considerable debate (e.g., Evans and Ilbery, 1993), here we consider only 'crop diversification' in dryland agriculture. Crop diversification involves the on-farm alteration of crop mixes, and perhaps the introduction, addition or substitution of new crop varieties. A mix of crop types with different climate-related characteristics (e.g., temperature, moisture, and heat requirements and tolerances) is expected to reduce the risk of income loss as a result of climate change better than a reliance on a single crop with particular characteristics and susceptibilities, especially when climate change risks include those associated with inter-annual variability and changes in the frequency and magnitude of droughts. It should be noted, however, that the utility of crop diversification varies, depending on farm and farm production characteristics. For example, crop diversification as an adaptation may have considerable utility for highly specialized producers, but may have limited utility for producers with already diversified operations.

Diversification across crop types is intended to spread exposure of climate-related risks and therefore reduce the vulnerability of crop agriculture to various climate stimuli and other environmental perils such as disease and pests. Given that differing characteristics of crop varieties are reflected in disparate vulnerabilities and resiliencies to climate change conditions, crop diversification is considered a *moderately effective (4)* adaptation option, especially in the case of specialized production. According to this hypothetical example, crop diversification reduces the risk of income loss as a result of climate conditions to some extent, but is not considered highly effective because climate change may still impact some crop varieties, likely leading to some income loss. Moreover, for farms that are already diversified, crop diversification would be a *moderately ineffective (2)* adaptation option.

In terms of *economic efficiency*, crop diversification is *moderately effective (4)*, as the benefits of reduced income loss are expected to exceed the costs of implementation. There are some additional costs expected with growing a wider variety of crops, including the possible additional farm equipment (e.g., for planting, harvesting, storing, etc.) and labour costs, which are dependent on the nature of the change in cropping practices. 'Economic efficiency' studies have shown that crop diversification also produces a cost in terms of lost economies of scale (Bradshaw *et al.,* 2001). Furthermore, some income loss may also result in good climate years if some of the selected crops grown are not as highly valued as other specialized crops. However, many types of diversification, including over different varieties of a common crop, incur only moderate marginal costs.

Crop diversification is also a *very flexible (5)* adaptation option, given its potential for yield production under a variety of climate conditions, whether climate change is manifest in a change in the frequency, magnitude or timing of moisture availability. Diversification across crop types will usually be of some help under most forms of variable climate conditions.

Crop diversification in dryland agriculture has *high institutional compatibility (5).* It is already encouraged in Alberta under various provincial and federal programs; those administered by the Prairie Farm Rehabilitation Administration (PFRA) under the *Federal Prairie Farm Rehabilitation Act*, for example, promote crop diversification. Notwithstanding this institutional support, crop choice is essentially an individual responsibility, independent of formal approvals.

Crop diversification has neither high nor low *farmer implementability (3)* given current social and cultural norms. Farmers may be discouraged by the potential complexity of the practice, the need to change established practices, attitudes and norms and additional equipment or contracting, and the potential demands on time, knowledge, and resources for production and marketing. While crop diversification as an adaptation may be difficult to implement for some farmers, it rarely requires major farmer training or investment, and is often readily implementable. Thus, it is considered to have neutral farmer implementability.

Crop diversification has *independent benefits* (4) because, in addition to reducing the risks associated with climate changes, it reduces risks associated with variability in input costs and commodity prices. Furthermore, crop diversification can offer improvement in soil fertility and reductions in pesticide use through improvements in natural pest resistance.

7.7.2 Adaptation Option 2: Implementation of Irrigation (Technological Adaptation)

While irrigation agriculture involves only a small proportion of Alberta's total crop agriculture, it continues to expand almost entirely within southern Alberta's 13 irrigation districts (Johnston *et al.*, 2001). Where feasible, irrigation allows for improved agricultural productivity (e.g., increased yields over what is expected from dryland agriculture) and enables selection of a wide range of crops grown in warmer and more arid regions, such as sugar beets, soft spring wheat, and potatoes (Alberta Agriculture, 1999-2001). Wheat remains the dominant irrigated crop in southern Alberta, followed by barley and alfalfa (Johnston *et al.*, 2001).

Alberta's Water Act governs the allocation of water for all uses, including licenses for irrigation water withdrawals. However, in southern Alberta, irrigation districts, under the *Irrigation Districts Act*, govern the licensing of water rights for farms. Structural diversions or 'headworks' play a large role in providing water supplies for irrigation agriculture and their construction has long been heavily subsidized by the Alberta government (Kromm, 1991). The costs of developing new infrastructure or upgrading existing infrastructure within existing irrigation districts are shared between the provincial government (75%) and the specific irrigation district in question (25%). A number of irrigation-related structures located outside the districts are also owned and operated by the province. Farmers with land within an irrigation district apply directly to that district for water rights. If the land in question is outside one of the provinces's 13 existing irrigation districts, the land owner would apply to Alberta Environment directly for a license to draw water directly from a river or stream in accordance with Alberta's Water Act.

In this hypothetical case example, the implementation of irrigation is an adaptation option for the purpose of reducing risk of income loss due to recurring drought. Switching from dryland agriculture to irrigated agriculture will reduce the risk of yield losses, as moisture can be artificially added in times of moisture stress with benefits for reducing income-related risks so long as the cost of irrigation is not too great. Of course, adoption of irrigation as an adaptive strategy is an option only available to farmers in locations where there is water available, where the infrastructure for its distribution is in place, and where the management, licensing and pricing arrangements make irrigation feasible.

Implementation of irrigation, where feasible, is a *very effective (5)* adaptation option. Irrigation will allow for the artificial application of moisture during times of stress and will maintain and perhaps enhance crop yields relative to climate conditions. However, attaining water rights may not be feasible for some areas of Alberta given the characteristics of the land and the threat of diminishing water supplies and availability (Johnston *et al.*, 2001). Furthermore, sufficient water supplies in the future are also questionable given the realities of supply and demand. Therefore, in some cases, irrigation would not be feasible, and the adaptation would be *very ineffective (0)*.

Table 7-2 Criteria Scores and Selected Farmer Adaptation

	Reduce risk of losses due to increased frequency and magnitude of drought		
Criteria	**(1) Crop Diversification**	**(2) Implementation of Irrigation**	**(3) Increase Reliance on Crop Insurance**
	Score	***Score***	***Score***
(1) Effectiveness	2/4[(a)]	0/5[(b)]	4
(2) Economic Efficiency	4	0/4	5
(3) Flexibility	5	4	5
(4) Institutional Compatibility	5	0/4	5
(5) Farmer Implementability	3	3	5
(6) Independent Benefits	4	0/5	4

(a) Split scores denote criteria performance under different local or situational scenarios, in this case between diversified and specialized cropping operations; (b) Split scores distinguish situations where irrigation water is not available from those where it is available.

It is expected that considerable up-front costs will be required for irrigation implementation, such as the purchase of irrigation equipment and on-farm distribution infrastructure, and the purchase of new inputs to produce the higher value crops that benefit from irrigation. While other costs associated with pumping and water allocation volumes will be incurred, they contribute only a very small proportion of the total costs of irrigation implementation (Johnston *et al.*, 2001). Thus, irrigation implementation is considered to be *moderately economically efficient* (4).

While irrigation is a farm-level practice, the costs of facilitating irrigation are not necessarily an individual responsibility. For example, Alberta subsidizes irrigation infrastructure and supply works, particularly in the province's 13 irrigation districts, allowing for the costs of irrigation development and water supply to be publicly shared. The difference between farmers paying the full costs of water supply and delivery versus farmers assuming only a portion of these costs is potentially great. Thus, the costs of irrigation to the farmer vary depending on whether or not irrigation supply works are publicly subsidized. In areas where irrigation is feasible (i.e., irrigation infrastructure subsidized by province), benefits to the farmer are expected to be considerable through decreased damage losses due to drought. However, for those farmers outside an existing irrigation district, the costs of implementation may be very high, and perhaps prohibitive. Depending on the nature of the water supply infrastructure required, the characteristics of the irrigation system, pricing arrangements and any changes to farm structure and land use needed, irrigation as an adaptation option may be *very economically inefficient (0)* for some farmers.

In this hypothetical example, the *economic efficiency* of switching from dryland agriculture to irrigated agriculture is considered to be *moderately high* as the discounted economic benefits of reduced damages and income loss are exceeded by the discounted costs of implementation. We assume here that for any new irrigation (as an adaptation), farmers would have to assume only a portion of the costs. The relationship between benefits and costs here are represented as a ratio (1:0.9) over a five-year period. Given a longer time-frame (i.e., 12 - 15 years), the benefits of irrigation adoption may be much higher than the discounted up-front costs of initial implementation.

Implementation of irrigated agriculture is considered moderately *flexible (4)*. If water is available for irrigation, the adaptation is considered flexible under a variety of moisture constraints over a five-year period. However, given the uncertainties in predicting local and regional changes in precipitation, evaporation and the amount of available soil moisture, implementation of an irrigation system is not a flexible adaptation strategy, particularly in the case of surprise events. Drier conditions will undoubtedly have repercussions for water availability and recharge. Thus, moving from dry-land agriculture to an irrigated system may not be flexible, particularly when the depletion cycle further limits water availability and access for irrigation practices (Gabriel and Kreutzwiser, 1993). Furthermore, the adoption of irrigation does not leave room for the implementation of many other alternatives to respond to climate change effects in the future, particularly if water availability is reduced and allocation restrictions are implemented. Thus, given the potential for future water supply constraints due to recurrent and more extensive drought conditions as a result of climate change, irrigation agriculture over a longer-time period (more than the five years assumed here) is likely inflexible.

While the Alberta government in the past has encouraged the adoption of irrigation for improved crop productivity and diversity, the realities of limited water supplies due to mounting water demands have constrained irrigation expansion in southern Alberta. Therefore, in areas of significant water scarcity, the implementation of irrigation is considered to be *institutionally incompatible (0)*. However, for farmers in irrigation districts that have excess water capacity, and where land is deemed irrigatable and in close proximity to irrigation infrastructure, institutional compatibility may be considered *moderately high (4)*.

Farmer implementability of irrigation is *neutral (3)*. A change from dryland farming to irrigation agriculture will require substantial investment in time to learn new skills related to irrigation management given the specific soil and land characteristics of the farm property and the nature of the crop types intended to be irrigated. While technology is constantly changing, requiring continued learning, the greatest investment in time will be the initial stages of irrigation implementation (e.g., within the first few years of implementation), rendering farmer implementability low (steep learning curve). On the other hand, irrigation as an adaptation may require little additional learning and effort, especially if farmers have irrigated in the past (e.g., other farm properties, adjacent fields, etc.). Therefore, farmer implementability may be high given that an experienced farmer is well beyond the initial stages on the learning curve.

Irrigation, if feasible, has very high *independent benefits*. Irrigation will enhance the productivity (i.e., increase yields) of many crops irrespective of climate change and these benefits are expected to accrue within a five-year time period.

7.7.3 Adaptation Option 3: Increase Use of Crop Insurance (Financial Adaptation)

Many public sector programs relating to income stabilization, including crop insurance, exist at both the federal and provincial levels, and have indirect effects on how farm productivity and income are sensitive to climate change effects and how farmers adapt (Smit, 1994). Crop insurance regulations fall under the federal *Farm Income Protection Act* (FIPA), which authorizes federal-provincial government agreements to protect the income of agricultural producers by subsidizing approximately 50% of the value of insurance premiums. Alberta Crop Insurance is one type of risk management strategy that provides insured farmers with income on crop losses resulting from natural perils, including drought (except under irrigation) (Alberta Agriculture, 1999-2001). Participation in crop insurance represents a type of farm-level adaptation. Farmers may adapt to changing climate conditions by taking on or dropping insurance, or by varying the level of insurance that they buy. Research has shown that farmers vary in their use of crop insurance, and often this investment reflects recent climatic experience (Smit, 1994; Smit *et al.*, 1996). Thus, an increase in the use of crop insurance (i.e., from 60% to

80% coverage) while remaining in dryland agriculture is considered an adaptation option to reduce the individual risk of income loss due to increased drought frequency. While farm-level crop yield losses may result from increased frequency of drought, actual income loss will be reduced due to insured payouts.

Increased use of crop insurance is considered to be a *moderately effective (4)* adaptation option, because income loss due to increased incidence of drought is reduced. While an effective risk management strategy to protect income loss, crop insurance does not ensure that the total value of crops are reimbursed and with repeated crop losses, the base for payout may be reduced. That is, farmers may lose some income due to crop damage as a result of climate changes even with increased crop insurance. Therefore, increasing reliance on crop insurance may still result in some moderate income loss, although much less so if the full burden of crop damage costs were assumed by the individual farmer. Furthermore, the government provides 50% of the value of insured premiums (i.e., the premiums are subsidized). It should also be noted that the basis of crop insurance payout is sensitive to a farmer's recent history of production, so that recurring drought-related losses will gradually reduce the effectiveness of crop insurance as a strategy.

Increased use of crop insurance (e.g., increasing coverage from 60% to 80%) is considered to have high *economic efficiency (5)*. Coverage for each type of crop is set by producer risk area, is dependent on the individual producer's production history, and is determined by crop type and price options. While the adaptation requires an economic investment or commitment by an individual farmer, the premiums are shared between the producer and the federal and provincial governments. As a result, the full cost of crop insurance premiums is shared publicly. Furthermore, a variety of premium discounts are available for farmers, based on such things as past participation in crop insurance, number of insured acres and insurance of all crops (Alberta Agriculture, 1999-2001). Given that income loss is reduced as a result of increased crop insurance coverage and the shared premium costs of crop insurance, the economic costs to an individual farmer are expected to be far exceeded by the benefits of reduced income over a five-year period. However, the fact that increased insurance claims will likely be the result of increased drought frequency, insurance premiums may also subsequently increase. Therefore, the benefits of reduced income loss may only moderately exceed the costs of crop insurance premiums over a longer period.

Increased use of crop insurance is a *very flexible (5)* adaptation option as most crops can be insured, insurance is on a crop-by-crop basis, and the insurance offers coverage against all kinds of crop damage/losses resulting from drought.

Increased use of crop insurance is considered to have high *institutional compatibility (5)* as insurance programs are already in place and are encouraged by the provincial and federal governments.

Increased use of crop insurance has high *farmer implementability*. It requires little additional learning, skills or alteration in current practices, especially when relied on in the past for risk management. The primary change involves changes in the levels of coverage and premiums paid out by the farmer.

Increased use of crop insurance, while a strategy that reduces income loss as a result of climate-related perils, including drought, would still be applicable if climate conditions do not change, or if the change in frequency reduces the ability of farmers to continue to buy into crop insurance at a particular premium level but the benefits would be modest. Essentially, crop insurance provides 'peace of mind' to farmers and is only paid out in times of crisis due to a natural hazard. Thus, increased reliance on crop insurance has moderate *independent benefits (4)*, because even without climate change there will be drought, but crop insurance does not help with non-climate perils.

7.7.4 Multi-Criteria Evaluation of Private Agent (Farmer) Adaptations

The results presented in Table 7-3 illustrate how each adaptation performs for each criterion. Crop diversification as an adaptation scored high on flexibility and institutional compatibility. It is a very flexible adaptation given a variety of climate-related conditions and can be readily implemented under current institutional frameworks. The effectiveness of crop diversification as an adaptation is variable. Since some farms will already be diversified, crop diversification could be ineffective as an adaptation to climate change.

Implementation of irrigation as an adaptation was variable across the evaluative criteria. If water availability is limited, if land proposed for irrigation is located outside an irrigation district, and if infrastructure is not subsidized by the province, implementation of irrigation as an adaptation scores zero for effectiveness, economic efficiency, institutional compatibility and independent benefits. On the other hand, if these conditions are met, then irrigation scores much higher across these above-mentioned criteria. Flexibility and farmer implementability scores remain the same across the different scenarios.

Increased use of crop insurance scored high among all the criteria. As an adaptation option, increased use of crop insurance is especially economically efficient, given that approximately 50% of the value of premiums is covered by the provincial and federal governments, and flexible, since it can be used under a variety drought conditions. Furthermore, increased crop insurance is readily available and requires little additional effort and learning. Therefore, as an adaptation option, it is especially compatible institutionally and implementable at the farm level.

According to a simple sum of the scores, the adaptation with the greatest overall merit was increased use of crop insurance, followed by crop diversification and implementation of irrigation using the high-scenario scores. Increased use of crop insurance received the highest value (based on the five-point scale) for four out of the six criteria. For the other two criteria its performance was considered moderately high (4). When the low-scenario scores were incorporated into the algorithm (a score of 0 for effectiveness, economic efficiency, institutional compatibility, and independent benefits), implementation of irrigation received the lowest summed score. With the incorporation of the lower criterion score (a score of 2 for effectiveness), crop diversification was considered to have greater merit than irrigation implementation according to the simple sum of scores.

Using the weighted sum method (using the weights established earlier), the overall rank of the adaptations changes slightly (Table 7.3). Increased reliance on crop insurance received the highest score, followed by implementation of irrigation and crop diversification (assuming the best-case-scenario scores). Thus, assigning weights to the criteria, in this case a higher priority assigned to effectiveness and economic efficiency, improved the relative merit of implementation of irrigation (using the high-scenario scores only). Had the weights been arranged differently, the relative overall merit of adaptations may have been different.

Another approach to evaluating the adaptations across the multiple criteria is to rule out adaptations based on very low scores on specific criteria, regardless of overall sums (Maclaren, 1985). In this case, a farmer is not likely to implement an adaptation measure if it is not effective (i.e., if it does not reduce the risk of income loss), regardless of how flexible, how institutionally compatible or even how economically efficient it is. If an adaptation is not effective, it will likely not be adopted. Similarly, if an adaptation option is not economically efficient (i.e., benefits do not exceed costs), the likelihood of it being adopted is also reduced, regardless of its performance across other criteria. For example, for a majority of dryland farmers in Alberta, irrigation is not a feasible option given supply uncertainties and limitations, proximity to supplies and distribution infrastructure, and other institutional constraints. Therefore, for those farmers, irrigation implementation as an adaptation option is not feasible regardless of the scores received for other criteria.

Table 7-3 Results of Evaluation (Private Agents)

	Reduce risk of income loss due to crop failure as a result of increased moisture stress					
Criteria	**(1) Crop Diversification**		**(2) Implementation of Irrigation**		**(3) Increased Use of Crop Insurance**	
	Score	***Weighted Score***	***Score***	***Weighted Score***	***Score***	***Weighted Score***
(1) Effectiveness (3)[(a)]	2/4[(b)]	6/12	0/5	0/15	4	12
(2) Economic Efficiency (3)	4	12	0/4	0/12	5	15
(3) Flexibility (1)	5	5	4	4	5	5
(4) Institutional Compatibility (1)	5	5	0/4	0/4	5	5
(5) Farmer Implementability (1)	3	3	3	3	5	5
(6) Independent Benefits (1)	4	4	0/5	0/5	4	4
SUM	**23/25**	**35/41**	**7/25**	**7/43**	**28**	**46**

(a) ( ) Indicates weight assigned to criterion; (b) Split scores denote criteria performance under different local and situational scenarios.

7.8 Evaluation of Public Agent (Government) Adaptations

The evaluation of government adaptation initiatives can be undertaken from two different, but often inter-related points of view: the individual producer (farmer) and the general public (government). The results of the evaluation of public adaptations are presented in Table 7-4.

7.8.1 Adaptation Option 1: Increase Investment in Income Stabilization Programs

The Department of Agriculture and Agri-Food Canada provides a portfolio of programs, policies and regulations that help the agriculture and agri-food sector to develop, adapt and remain competitive in the global economy (see for example the Canadian Adaptation and Rural Development (CARD) National Initiatives). Income stabilization programs, such as the Net Income Stabilization Account (NISA), are authorized by the *Farm Income Protection Act* (FIPA) and are designed to assist farmers in achieving long-term whole-farm income stability in light of variable production and market conditions, irrespective of the commodities produced. As part of Canada's farm safety net framework, NISA allows farmers to deposit up to 3% of their Eligible Net Sales (ENS) into a NISA account where the federal and provincial governments will together match this amount. Farmers can withdraw from their NISA accounts when their farm's current year *Gross Margin* (based on net sales of agricultural commodities minus eligible expenses) falls below the *Gross Margin* average from previous years (up to five years). Thus, once the individual accounts are sufficiently established, farmers may draw on the account under a variety of circumstances, including climate-related crop losses/damages.

In this case, the adaptation is taken as increased investment in income stabilization, representing an increase in the proportion of net sales (i.e., from 3% to 6%) that can be deposited into a NISA account by an individual farmer and will be matched by the federal and provincial governments. Therefore, the total available value of farm-level funds is expected to increase and be available for use as a type of personal income insurance in the event of drought-related crop/income losses. Thus, an increase in investment by both the federal and provincial governments into income stabilization will lead to more funds being available to farmers in order to reduce the risk of farm-level income loss as a result of increased incidence, severity and duration of drought conditions.

Increased investment into income stabilization by governments is a *moderately effective (4)* farm-level adaptation to drought risks. Farmers are able to draw on their NISA account when their annual income is below their five-year average. Thus, in the case of drought-related losses, farmers can access their personal accounts to supplement their reduced yearly income. However, the funds available in the account will be diminished with recurring droughts. As the time between NISA withdrawals decreases, the overall funds available to farmers for income stabilization will also diminish. Thus, the effectiveness of income stabilization for reducing the risk of income loss becomes diminished. From the point-of-view of governments, the adaptation option is *moderately effective (4)*.

Increased investment by the government into income stabilization is moderately *economically efficient (4)* for farmers. Farmers' contributions to their accounts are matched by federal and provincial contributions. Therefore, half of the economic investment is shared by the public sector, while the individual farmer benefits from the entire account. With increased contributions by farmers and governments, the available funds are increased and available when needed (i.e., income supplement as a result of crop losses). However, in the case of increased drought frequency, farmers still have to make contributions to their funds in order to take advantage of the income security. The more frequent and severe droughts become, the greater the likelihood that the benefits of income stabilization will be exceeded by the costs. From the point-of-view of the public, increased investment into income stabilization is *very ineffective* economically *(0)* because it requires additional economic investment of public monies for the intentional benefit of farmers, and may discourage other forms of farm-level adaptation.

Increased investment in income stabilization is a *very flexible (5)* farm-level adaptation option. Farmers are able to draw on their accounts when their annual income for a given year is below a calculated five-year average, regardless of the degree of damage/loss as a result of climate change conditions and regardless of the particular condition that created the loss. From the government point-of-view, income stabilization is also *very flexible (5)* in that it applies to any climate-related stimulus that causes losses.

Increased investment in income stabilization by governments is neither *institutionally compatible* nor *incompatible (3)*. The NISA program is currently delivered to farmers across Canada, including Alberta, and therefore few legislative or regulatory changes are expected; however, public sector acceptability to an increase in the 'public' subsidy for farm-level gain is not known, and any suggestion would be based on simple speculation. Therefore, the institutional compatibility of the adaptation is questionable and considered neutral according to the normalized scale.

Farmer implementability of this adaptation option at the farm-level is *moderate (4)* as few new skills are required of the farmer. The adaptation option does not involve technological or land management alterations, only some awareness and knowledge of the revised program, which is expected to provide greater income security to farmers and farm families. While the social benefits of income stabilization are obvious, experience has shown reluctance on the part of farmers to draw on their accounts in years of crop loss.

Investment in income stabilization is considered to have high *independent benefits (5)*. It offers income security to farmers irrespective of the commodity produced and regardless of the source of loss. Farmers can apply to access their accounts whether the cause of income loss is a result of climate changes (e.g., drought conditions), or of market-related conditions (e.g., declining commodity prices). Therefore, there are benefits of income stabilization to the farmer independent of climate change.

Table 7-4 Results of Evaluation (Public Agents)

Criteria	Reduce risk of farm-level income loss due to crop failure as a result of increased moisture stress					
	(1) Income Stabilization		(2) Modify Crop Insurance		(3) Promotion of Crop Development	
	Score		*Score*		*Score*	
	Farmer	Government	Farmer	Government	Farmer	Government
(1) Effectiveness	4	4	4	4	3	4
(2) Economic Efficiency	4	0	3	5	4	2
(3) Flexibility	5	5	3	3	3	3
(4) Institutional Compatibility	3	3	2	4	3	4
(5) Farmer Implementability	4	4	2	2	5	5
(6) Independent Benefits	5	5	2	2	2	2

7.8.2 Adaptation Option 2: Modify Crop Insurance Support

As a joint federal-provincial arrangement, crop insurance in Alberta enables farmers to insure their particular crop varieties against a variety of climate-related conditions, including drought. Programs, such as crop insurance, can be designed and modified to encourage farmers to plan ahead for the potential risks of climate change. Given the prospects of increased crop insurance claims because of increases in drought frequency, intensity and magnitude, governments may consider adapting their programs. A reduction in the proportion of crop insurance subsidized by governments represents an adaptation option that would be expected to encourage farmers to produce lower-risk crops, crops more adaptable to changing climate conditions, and/or a greater variety of crops to spread exposure to climate-related risks.

In this hypothetical case, an adaptation by a public agent is one where modifications are made (by the provincial and federal governments) to the current crop insurance terms of reference so that farmers will have to assume 75% of the costs of crop insurance, rather than only 50% (which is then matched by government subsidy). Therefore, government contributions to crop insurance are reduced from 50% to 25%, and it is expected that farmers will rely less on crop insurance and employ other adaptation strategies such as planting crop varieties more suited to drier conditions, representing a reduced risk of income loss as a result of climate-related damages.

Modification of crop insurance is a *moderately effective (4)* farm-level adaptation. A reduction in government subsidy for crop insurance for specific crops is expected to have any of several effects. For example, farmers may choose to use less crop insurance, to pay higher premiums for crop insurance, to change the variety of crops grown, or to adopt other strategies. In the case of changing the types of crops grown, farmers may choose varieties that are more drought-tolerant and heat-tolerant over higher-risk crops (i.e., not tolerant of drought and arid conditions), because they will have to assume a greater proportion of the risk of income loss as a result of crop damages.

This adaptation option is neither *economically efficient* nor *inefficient (3)* for farmers. While some farm-level investment is required if higher premiums are paid by farmers, it is expected that this economic investment is minimal compared to the benefits of reduced income loss that will be received. However, a change in crop insurance subsidies relative to past subsidies requires farmers to assume greater risk and a greater proportion of the costs of insurance premiums. While an obvious economic benefit (*high economic efficiency (5)*) to the taxpayer and governments (in decreased contributions to subsidies), the economic efficiency to the farmer is diminished relative to past arrangements.

Modification of crop insurance is neither *flexible* nor *inflexible*, but *neutral (3)*, as a decrease in insurance subsidy does not change the ability of farmers to take advantage of their insurance when damage has occurred as a result of climate changes. They are still able to receive payouts regardless of the degree of change in the frequency, magnitude or duration of drought.

Modification of crop insurance is considered to be moderately *institutionally incompatible (2)* from a farmer point-of-view. While crop insurance is already an integral component of agricultural systems, and modifications are primarily related to changes in the terms of reference, requiring limited changes to institutional structure, it is likely that farmers and farm organizations themselves may disapprove of the modifications and will attempt to constrain the changes. Thus, the institutional compatibility of the adaptation is diminished due to potential resistances by lobby groups and other social organizations. From the government perspective, decreasing the public share of contributions to crop insurance will likely be favoured and encouraged by the public sector. Thus, modification of crop insurance as an adaptation is considered *very institutionally compatible (5)* from the public (government) perspective.

Modification of crop insurance is considered to have *low farmer implementability (2)*. The modification of crop insurance is an incentive for farmers to be better equipped to deal with changes in the frequency of drought conditions. However, farmers may be discouraged to change their practices due to the complexity and effort needed in changing long-established practices, and the potential changes related to farm management and marketing. Furthermore, while the modification in crop insurance may provide an incentive to change farm-level cropping practices, it does not guarantee that all farmers will automatically see the advantages of adapting. Therefore, farm-level change is likely to be slow in the first five years of implementation of the adaptation by governments. Speed of diffusion will likely increase as more farmers make adjustments and as potential increases in the frequency of drought encourage adaptations.

Modification of crop insurance is considered to have *low independent benefits (2)* at the farm-level. While the implementation of practices more adapted to potential climate changes may also have benefits regardless of whether or not climate changes (e.g., different crops enable farmers to deal with changes in commodity prices), these benefits are likely to be marginal.

7.8.3 Adaptation Option 3: Promotion of Crop Development

Investment into agricultural research and development also represents a climate adaptation option by public agents. Governments can encourage the development of new varieties of plants that are heat-tolerant and drought-tolerant, which primarily involves the investment (by governments) in both public and private research and development. In this case, the public adaptation initiative is the investment of public funds into the development of new crop varieties more suited to warmer and drier conditions.

Investment in, and promotion of, the development of heat and drought tolerant crops varieties is considered to be a *moderately effective (4)* adaptation, given that the past trend in research and development has been to focus breeding on specific climate conditions, rather than on the ability of crops to cope over a range of temperature and moisture regimes. Also, there are limits in developing crops that have full drought tolerance without a notable loss of yield/income potential. Already a very wide range of crop types with differing climate requirements have been developed, yet these do not greatly help with inter-annual variability. From the point-of-view of a farmer, promotion of crop development is considered neither *ineffective* nor *effective (3)*. Effectiveness varies greatly depending on the particular crop type planted, and existing characteristics of the farm operation.

The adaptation is considered to have moderate *economic efficiency (4)* at the farm-level. From the farmer point-of-view, very little investment is required by farmers themselves. While implementing costs are not great, it is expected that there will be some yield/income costs to the farmer as a result of reduced yields and income during 'good years' (i.e., no moisture or heat stress) and reduction of crop losses (benefits) during drought years. Thus, unless breeders can develop resilience in crops without any yield trade-offs, the adaptation is only moderately economically efficient. On the other hand, investment in crop development is generally an investment by the public or taxpayers. Therefore, this adaptation is *economically inefficient (2)* from the government point-of-view, as the direct economic benefits of public investment are received by only a portion of the population (farmers).

Investment in crop development is considered to be only *moderately flexible (4)*. Given the difficulty breeders have in quickly advancing one attribute (e.g., moisture tolerance) and retaining all others at the same level, it is likely that new varieties may be adaptable to a variety of climate change conditions, but may also be more vulnerable to some conditions.

The *institutional compatibility* of crop development is *moderate* (4) from the point-of-view of government. There are potential constraints due to the 're-direction' of priorities in breeding research, and the willingness of governments/taxpayers to pay for these contributions. From the farmer's perspective, it is neither *compatible* nor *incompatible (3)*.

The promotion of crop development is considered to have high *farmer implementability (5)*, so long as there is little additional knowledge, skill and economic investment required at the farm-level. It is likely that few adjustments in farm practices, equipment and marketing will be required with the use of new crop varieties.

Promotion of crop development is considered to lack *independent benefits (2)*. Crop development, with a focus on resilience to drought, may simultaneously promote other beneficial attributes, but is just as likely to have some of these attributes as trade-offs.

7.8.4 Multi-Criteria Evaluation of Public Agent (Government) Adaptations

The results presented in Table 7-5 and Table 7-6 illustrate how each adaptation performs on the criteria. Income stabilization as a government adaptation scored highest on the flexibility and independent benefits criteria from both the farmer's and the government's point-of-view. Income stabilization is very flexible given that farmers can use the adaptation option regardless of the degree of damage/loss as a result of climate change effects and regardless of the type of condition that caused the damage. It is also considered to have very high independent benefits as it offers income security to farmers regardless of what they produce and of the source of income loss. Income stabilization from the farmer's perspective is considered neither institutionally compatible nor incompatible, given that there will be both acceptance and resistance to program changes. From the public point-of-view, investment in income stabilization scored very low on economic efficiency since the public or taxpayers will bear a larger proportion of the costs to farmers as a result of climate-related income losses.

Modification of crop insurance is considered moderately effective from the farmer's perspective, although it scored moderately low for institutional compatibility, farmer implementability and independent benefits. While it is expected to reduce farmer reliance on crop insurance and encourage adaptations in crop agriculture, it is also expected that many farmers would resist the institutional changes in the political arena, that the changes in farm practices would be slow due to the complexity and effort required, and that benefits regardless of climate changes would be marginal.

Table 7-5 Results of Evaluation (Public Agents): Farmers Point-of-View

Criteria	Reduce risk of farm-level income loss due to crop failure as a result of increased moisture stress					
	(1) Income Stabilization		(2) Modify Crop Insurance		(3) Promotion of Crop Development	
	Score	*Weighted Score*	*Score*	*Weighted Score*	*Score*	*Weighted Score*
(1) Effectiveness (3)[(a)]	4	12	4	12	3	9
(2) Economic Efficiency (3)	4	12	3	9	4	12
(3) Flexibility (1)	5	5	3	3	3	3
(4) Institutional Compatibility (1)	3	3	2	2	3	3
(5) Farmer Implementability (1)	4	4	2	2	5	5
(6) Independent Benefits (1)	5	5	2	2	2	2
SUM	**25**	**41**	**16**	**30**	**20**	**34**

(a) ( ) Indicates weight assigned to criterion.

Similarly, from the government's perspective, modification of crop insurance has low farmer implementability and low independent benefits. However, as an adaptation from the point-of-view of government, modification of crop insurance is very economically efficient. Less investment in crop insurance from the government translates into less economic investment by the taxpayer for the benefit of farmers. Similarly, it also scored well on the institutional compatibility criterion, since it is expected to have more support from the public sector than from farmers.

Promotion of crop development from the farmer's point-of-view scored very high for the farmer implementability criterion and moderately high for economic efficiency. Little additional skills or learning are required on behalf of the farmer making it a very flexible adaptation, and few implementation costs and some income losses to the farmer are expected, suggesting that it is moderately economically efficient. It scored moderately low for independent benefits and neutral for effectiveness, flexibility and institutional compatibility. From the point-of-view of farmers, a focus on drought resistance will likely involve some trade-offs in other areas of crop development (i.e., reduced investment in higher yielding crops).

Considering all criteria together using a sum of the scores aggregation method, the government adaptation with the greatest overall merit from the point-of-view of the farmer was income stabilization, followed by promotion of crop development and modification of crop insurance. Income stabilization received high scores (based on the five-point scale) across five of the six criteria. Modification of crop insurance received the lowest summed scored, primarily because it received moderately low scores for three out of the six criteria. Using the weighted sum method (using the weights established in Section 7.5), the overall rank of the adaptations from the farmer's perspective did not change.

Table 7-6 Results of Evaluation (Public Agents): Government Point-of-View

	Reduce risk of farm-level income loss due to crop failure as a result of increased moisture stress					
Criteria	**(1) Income Stabilization**		**(2) Modify Crop Insurance**		**(3) Promotion of Crop Development**	
	Score	*Weighted Score*	*Score*	*Weighted Score*	*Score*	*Weighted Score*
(1) Effectiveness (3)[(a)]	4	12	4	12	4	12
(2) Economic Efficiency (3)	0	0	5	15	2	6
(3) Flexibility (1)	5	5	3	3	3	3
(4) Institutional Compatibility (1)	3	3	4	4	4	4
(5) Farmer Implementability (1)	4	4	2	2	5	5
(6) Independent Benefits (1)	5	5	2	2	2	2
SUM	**21**	**29**	**20**	**38**	**20**	**32**

(a) ( ) Indicates weight assigned to criterion.

Income stabilization was considered to have the greatest overall merit according to the aggregated criteria.

From the government's point-of-view, income stabilization remained the best adaptation option, followed by investment in crop development and modification of crop insurance. There is far less variability among the adaptation options in terms of their overall merit when compared to the evaluation from the farmer's point-of-view. Income stabilization, while remaining the superior adaptation, was only slightly ahead of the other adaptations, as a result of it being considered economically inefficient from the government's point-of-view.

From the government's point-of-view, using the weighted sum aggregation, the overall rank of adaptations did change. Modification of crop insurance became the superior option, followed by promotion of crop development and income stabilization. The heavier weighting (3 out of 10) on economic efficiency improved the overall merit of modification of crop insurance and decreased the utility of income stabilization substantially relative to the other adaptations.

Similar to the discussion in Section 7.7.4, the adaptation options could have been evaluated by ruling out adaptations if they did not meet certain criteria, regardless of their performance on other criteria. This method could be employed prior to or after a weighted sum exercise is applied. For example, if an adaptation measure is deemed ineffective (i.e., receives a score of zero), its performance relative to other adaptations is irrelevant from the point-of-view of dealing with climate change risks. Similarly, economic efficiency can be considered a priority criterion, since economically inefficient adaptations are likely to be of little interest to farmers and governments, and are unlikely to be implemented regardless of whether they are institutionally compatible or have high independent benefits. In this case, economic efficiency might be considered a ‘ruling-out’ criterion for both governments and farmers. Income stabilization, for example, was economically inefficient from the point-of-view of governments. Therefore, it may be considered unacceptable regardless of its performance on effectiveness and other criteria.

8. Adaptation Evaluation and Decision-Making in Agriculture

The MCE is illustrated here at the 'generic level' of a private agent (i.e., farmer) and public agent (i.e., government). In both evaluations (i.e., private and public) the climate change risk was identified (i.e., increased frequency of drought), the initiator of the adaptation (e.g., who was adapting – farmers or governments) was distinguished, and the benefits of implementing the adaptations were evaluated using multiple criteria for both the individual farmer (private agent) and the government (public agent). The evaluation was intended to reflect the performance of adaptation measures according to multiple criteria, and not the *likelihood* of the adaptation measures being adopted by a particular farmer or government. If the intent were to evaluate the likelihood of the implementation of adaptation measures, the evaluation would have been more specific to the location attributes of the farm, personal characteristics of the farmer, and circumstances of the farm operation. Similarly, an assessment of the likelihood of implementation of options from a government point-of-view would have to consider political propensities and economic constraints of different levels of governments.

To be applied rigorously, evaluation frameworks of the types illustrated in this report would require considerable research. While dedicated projects could be initiated to generate reliable evaluations or scores on each criterion, it is likely that for each adaptation option, a wide range of evaluation scores would be generated, depending on the particulars of climate stresses, adaptation details and farm location and circumstances. The framework itself could also be subject to refinement to address the different scores depending on whether the evaluation is from the point-of-view of farmers, agri-business, governments, or citizens generally. The framework also could be refined with more comprehensive means of assigning criteria weights and with exploring alternative methods for aggregating over criteria, weighted or not. However, this kind of detailed evaluation of adaptation options not only has technical challenges, but it may not be appropriate or necessary at all given the way in which decisions are taken in the agricultural sector.

In the climate change literature, planned adaptations have been addressed primarily as if they constitute discrete measures (or actions, technologies or practices) that might be employed specifically to address known impacts (or vulnerabilities or risks) associated with climate change. The adaptation 'options' tend to be described as if they represent a clearly defined strategy, widely applicable and in a standard form, and hence subject to comparative evaluation. This implies (if not stated explicitly) that the evaluation process would identify, from a list of many options, those adaptations that are superior (or optimal, best, preferred, highly ranked, or recommended). The adaptation options are treated as if they can and should be evaluated (and, if shown to be beneficial, implemented) in light of climate change impacts alone. For the most part, they are also considered in a static manner, in the sense that the evaluations assume an instantaneous adoption of adaptation measures.

Such expectations are reasonable given the modest research to date on adaptation processes in the climate change field. Yet research in farming systems and agricultural decision-making, and international scholarship on the characteristics and processes of adaptation demonstrates the need to recognize the dynamic decision processes within which choices about adaptations will be made. To illustrate the implications of this for adaptation evaluation, consider some examples.

A particular adaptation 'option', such as irrigation or crop diversification, can take many different forms and generate quite different evaluations. When the different circumstances of particular farms and farmers are considered, a single adaptation 'option' can take on even more manifestations, each with quite different evaluations. Hence, a seemingly straightforward adaptation option such as 'crop diversification' considered for a relatively homogeneous type of agriculture (in this case dryland crop farming in southern Alberta) will, in reality, mean something different, and be evaluated differently, according to:

- the type of climate change stimuli considered (e.g., gradual increase in average temperature and moisture deficits, increased drought frequency, increased drought severity, etc) and other biophysical conditions (e.g., soil type)

- the type of dryland farming, e.g., if already diversified, then 'crop diversification' will have little effectiveness as an adaptation, whereas if the farm is quite specialized, effectiveness will likely be different

- the means of introduction/adoption, e.g., the evaluation would likely differ depending on whether diversification was simply the farmers' choice or encouraged by some incentive (e.g., promotion of or subsidy for diversification) or by some disincentive (e.g., removal of a crop-specific support program). Implementation of different crop types is also dependent on, and will differ according to, availability of marketing channels and market prices for 'new' crops.

Furthermore, crop diversification as an adaptive response to climate risks faces as variety of potential constraints. If the end goal is income security, off-farm income diversification (e.g., off-farm work) may represent a more effective strategy (Bradshaw *et al.*, 2001). When these possibilities are considered it is quite possible for the adaptation 'options' of 'crop diversification' in dryland farming in southern Alberta to have wide ranging evaluations from very positive to very negative.

The examples employed in this respect illustrate that MCE is technically possible, but that to evaluate in more than a superficial fashion, applications would need to be considerably more specific (i.e., separate for different farm types, locations, and climate change stimuli) and would need to explicitly consider temporal scales (i.e., short versus long-term).

Those adaptations that involve multiple actors (e.g., governments, business, farmers), such as changes in technical or public support programs, are particularly difficult to evaluate because the assessments can differ greatly depending on whether the evaluation is undertaken from the point-of-view of the farmer, the agri-business, or the government.

Yet, even if adaptations were specified precisely, and evaluated separately for each group of stakeholders, or even undertaken at the level of individual farms, the evaluation exercise still has limited applicability to the reality of farm decision-making. Most of the 'adaptation options' are not only 'adaptations to climate change', but also practices or methods that affect other aspects of the farm production system, and are sensitive to conditions other than climate. Farmers and decision-makers in agri-business and government agencies rarely assess production choices and management strategies in light of climate change risks alone, and these assessments and decisions tend to be on-going, subject to inertia, yet frequently re-evaluated and modified as conditions change, as part of the dynamic decision process (Brklacich *et al.*, 1997b; Chiotti *et al.*, 1997; Bryant *et al.*, 2000). This realization that options to adapt to climate change are not undertaken outside the established decision processes , and that evaluations of adaptation options should similarly be undertaken in light of these broad decision processes, is now well established in some sectors (e.g., in the water resource sector, adaptation to climate change is seen as part of on-going risk management decision-making (Stakhiv, 1996)). To illustrate this for the agricultural sector, consider decisions made by farmers, crop breeders and government agencies, respectively.

A farmer's choice to change crop mix is not a one-off, discrete decision, nor is it made as a response to climate change risks alone. Rather, each year farmers decide on crops to grow and inputs to employ, and these decisions are based on, among other factors, personal circumstances, perceptions of markets, prices, costs, and government programs. Thus, the role of 'crop diversification' as an adaptation to climate change would be considered, if at all, in light of these other concerns in an on-going decision process (Bradshaw *et al.*, 2001). So any practical evaluation of adaptation options should be undertaken in this context, i.e., how climate change risks might alter the evaluation of production choices (e.g., crop diversification) already being considered for other reasons.

Decisions by crop breeders on what traits to breed for are based on an estimation of those traits for which there is a market (e.g., yield or product quality, chemical resistance, disease resistance, etc.). Climatic considerations are currently included in crop breeding only to the degree that crops are selected for the 'normal' growing season conditions in particular regions, and trials are conducted in the 'climate' that happens to be experienced in the one to three years of crop trials. There is little, if any, crop breeding directed to developing varieties that can better withstand variable climate or a wider range of climatic conditions (Smithers and Blay-Palmer, 2001; van Herk, 2001). Indeed, if climatic conditions happen to deviate from 'norms' during a trial period, then this is currently considered a problem, rather than an opportunity, for crop breeding.

Changes in government programs dealing with disaster relief represent a form of adaptation to climate change. Governments continually review and modify such programs in light of recent history, public opinion, general economic conditions, farm lobbying, international trade agreements, and so on. Increasingly, farm 'safety net' programs have moved away from being tied to particular types of risk or loss (e.g., climate-related) to more general income-support forms. Some requirements to provide non-specific income-support programs exist under international trade agreements. As a result, changes to such programs are undertaken in light of shifts in agricultural prices and costs, levels of support in other countries, the financial state of government coffers, etc. and perhaps relative to climate risks (e.g., probability of drought), but certainly not in light of climate change risks in isolation. At best, climate change risks would be an additional consideration in the assessment of public policy options regarding disaster relief. Both for private (farmer) and public (government) decision-making, evaluations of adaptations to climate change risks need to be taken as part of the on-going assessment of choices in light of climate and other risks (Wandel and Smit, 2000).

9. Conclusion

A large number and variety of potential measures to adapt to climate change risks exist. In the literature, a common request is for methods or frameworks to evaluate alternative adaptation options. The expectation is that such tools will at least assist in screening potential adaptation measures, and provide direction as to which adaptations should be encouraged or implemented. This report has described a consistent and systematic method to evaluate agricultural adaptation options, and in doing so, distinguished between the adapter (i.e., who is adapting) and the beneficiary of adaptation (i.e., who is benefiting from the adaptation), an exercise often neglected in adaptation assessments. We have also shown that, while it is possible to apply an evaluation consistently, it may not be the most practicable or necessary exercise given that decisions or 'adaptations' represent facets of on-going management (and risk management) decisions in the agri-food sector. Climate change risks are experienced in the context of a wide range of other conditions, and the evaluation of options to adapt to such risks is likely to be undertaken in the context of these broader decision processes.

Hence, quite apart from the technical challenges of MCE, and notwithstanding the information MCE can provide about the relative merits of adaptation options, the evaluation of adaptations to climate change, if intended to contribute to decision-making in the agri-food sector, must be included as part of the broader evaluation of measures and practices in this sector. A useful exercise in this regard is to consider how climate change risk management options fit into the more general framework of agricultural decision-making.

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